GAP ANALYSIS OF FISH IN THE HYDROLOGIC

UNIT 12090205 OF CENTRAL TEXAS

by

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A THESIS

IN

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ABSTRACT

GAP analysis has been successfully used to predict the biodiversity and develop conservation priorities on land on a broad scale since 1987. Its application to aquatic ecosystems started in New York in 1995 on a watershed scale and in Missouri in 1997 on a statewide scale. No complete standard method is currently in use.

This project attempted to apply GAP analysis to the eight-digit hydrologic unit 12090205 of the Colorado River basin in central Texas to identify and prioritize opportunities for conserving fish biodiversity in the riverine ecosystems, and to demonstrate the feasibility of applying the GAP analysis approach to the aquatic ecosystem in Texas.

The regular GAP analysis procedures were followed in the study. Sampled fish data were compiled and put into a customized Microsoft Access® relational database. The watershed-wide "known" distribution maps were produced by geographically linking each sample to the National Hydrologic Dataset (NHD) which allows the graphical display of sampling locations, and spatially cross-referencing these data in a tabular format. The riverine ecosystems were classified into Valley Segment Types using ArcGIS® (Environmental Systems Research Institute, Inc.). The eight variables for the classification were Size, Size Discrepancy, Gradient, Valley Wall Interaction Points, Flow, Rocktype, Floodplain and Land Use/Land Cover. Additional auxiliary attributes, Lowland, Soil pH, Pool, Lake, Backwater, Gravelpits, Mouth and Sewage, were also assigned to each segment. Habitat affinities were compiled and extracted from a number of available sources. New habitat-affinity information was also generated from the sampling database in conjunction with the valley-segment datalayer. Habitat-affinity models were then created using Structured Query Language (SQL) and were used to predict species occurrence on valley segments for each species known to occur in the study area. Logistic-regression models also were developed and employed to predict of species occurrence for the purposes of references and comparison. The variables Water Quality, Land Use/Land Cover, Road/Rail Road and Dam were used to classify the valley segments to develop an index of environmental quality for fish. The environmental quality index, the predicted fish biodiversity and the number of fish species of special concern (i.e., endemic to Texas, endangered/threatened and with a state rank from S2 to S4) were combined to develop the conservation priority ranks for each segment. The segments with a prior conservation rank were calibrated with the current conservation status and feasibility.

The results show that 1) the segments with high environmental quality are in Barton Creek, in the upper portion of Onion Creek and in the Balcones Canyonlands; 2) predicted fish diversity is expected to be highest in midsized streams; and 3) three groups of segments were identified as candidate conservation sites. They are i) the lower portion of Barton Creek, ii) the group of segments including three segments of Colorado River, Coldwater Creek, and three adjacent segments, and iii) two lower segments of Onion Creek and two segments of Colorado River right downstream of the City of Austin. The segments with high conservation priority after calibration are in the second group, and they are the gap for conservation; 4) the GAP analysis approach used in this study was shown to be a feasible method for developing conservation priorities in central Texas.

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CHAPTER I
INTRODUCTION

Overview and Objectives

Texas' freshwaters are inhabited by 45 families and 247 species of fishes (Hubbs et al. 1991). This is approximately 33% of all known freshwater species in the U.S. Texas Parks and Wildlife Department (TPWD) lists more than 20 of those species as threatened or endangered. Nearly half of the native fish species in Texas' Southern Deserts ecoregion (west of the Pecos River) are threatened with extinction or are already extinct. Five species in Texas have become extinct and three other species have been extirpated from their ranges. Humans have introduced 18 non-native or exotic species in Texas.

An intensive long-term study of the fishes of Texas compared the results of statewide surveys of freshwater fishes in 1953 and 1986. These studies were conducted at the same sites using the same sampling methods. Results suggest that 20% of freshwater species need conservation efforts and that fish communities in many regions of Texas have become more similar to each other because of human impacts (Buzan 1997).

According to the American Fisheries Society's Endangered Species Committee, Texas is one of the most inhospitable places in the United States for fish species. The state has lost six species of fish since 1900 and four since 1980. In 1997, 25 fish species were on Texas' endangered and threatened list. Concern over the decline in freshwater fish species in the late 1800s helped create Texas' first conservation institution—the Office of Fish Commissioner.

However, because the Fish Commissioner had limited resources and authority, the office did little to improve conditions for fish species. Instead, the Fish Commissioner attempted to compensate for the decline in native species by introducing European carp (*Cyprinus carpio*) to Texas.

The declines in fish biodiversity (Ehrlich and Wilson 1991) driven by anthropogenic alteration, fragmentation and loss of habitat (Wilson 1988) have prompted efforts aimed at developing of laws and policies for sound biodiversity conservation planning (Naveh and Lieberman 1994, Bojorquez-Tapia et al. 1995).

Past approaches to dealing with the problem have included: 1) Single-Species/Game-Species Management (with numerous success stories, but in some instances efforts worked to the detriment of native communities); 2) Clean Water Act (effectively dealing with major water-quality problems); and 3) Endangered Species Act (a necessary, but reactionary, costly and divisive approach to conservation) (Meixler et al. 1999).

What is needed is an objective and proactive approach to identifying and prioritizing where conservation efforts should be focused, including focusing on broader spatial scales and higher levels of biological organization. Problems associated with loss of habitat, hydrologic modifications, fragmentation, exotic species, disruption of ecological processes should be addressed.

The GAP approach

Geographic information systems (GIS) are increasingly used in biodiversity conservation planning (Norton and Williams 1992, Tucker et al. 1997). GIS models that could reliably predict biotic assemblages from landscape attributes would be particularly valuable in regions where biological surveys have not been completed or would be difficult to accomplish (e.g., Kirkpatrick and Brown 1994, Bojorquez-Tapia et al. 1995).

The use of GIS models to predict biotic communities has primarily involved terrestrial environments (e.g., Scott et al. 1993, The Nature Conservancy 1994, Bojorquez-Tapia et al. 1995). Gap Analysis was developed in 1988 and quickly became the largest effort ever mounted to map the biological resources of the United States. The gap analysis approach (Scott et al. 1993) uses maps of vegetation and predicted animal distributions to locate centers of species richness outside areas currently managed for biodiversity protection. These are considered the "gaps" of Gap Analysis. They are assumed to be critical for the protection of biological resources. Far less attention has been paid to the development of models for the prediction of aquatic communities (Angermeier and Winston 1999) due primarily to the difficulty in developing an analog for the Gap Analysis vegetation map that is used to classify habitat types. Most of the existing aquatic habitat classification efforts are hierarchical (e.g., Frissell et al. 1986, Moyle and Ellison 1991, Rosgen 1994; Angermeier and Schlosser 1995, Maxwell et al. 1995, Higgins et al. 1998), have extensive data requirements (e.g., Ellison 1984, Bazata 1991, Meador et al. 1993, Seelbach et al. 1997), vary in methods among flowing and standing waters, or are based on only a single landscape attribute (e.g., Lotspeich 1980, Aadland 1993). Thus, although many elements of an aquatic GIS for conservation planning are available, no complete method is currently in use.

Currently, a single-watershed pilot in New York has developed initial methods and protocols for an aquatic GAP. A statewide project in Missouri to extend the methodology for large geographic regions is also developing. Several states (Ohio, South Dakota) have initiated aquatic GAP. By the time this thesis was finished (August, 2004), Ohio and the Great Lakes finished a large part of their GAP programs. Texas has not started an aquatic GAP program.

The purpose of this study is to use the GAP approach for local or state planning and management to identify and prioritize opportunities for conserving fish biodiversity in the riverine ecosystems of an 8-digit Hydrologic Unit (HU 12090205) of Texas. The study will focus on a macrohabitat scale. Seelbach et al. (1997) identified the stream valley segment as the basic ecological unit for streams. This unit is based on forest ecological theory regarding mapping ecological units (Barnes et al. 1982; Spies and Barnes 1985; Rowe 1991; Rowe and Barnes 1994), as well as on aquatic ecological theory regarding zonation in streams (Sheldon 1968; Vannote et al. 1980). The length of a valley segment depends on the variability of the landscape and on stream size, but it is generally between 5 and 30 km. The study will identify the valley segments appropriate for fish conservation and it will attempt to demonstrate the feasibility of applying the GAP analysis approach to the aquatic ecosystem in Texas.

Study Area

The HU 12090205 is an eight-digit watershed located in the Colorado River Basin of Central Texas near the city of Austin (Figures 3, 4). Fifty-three percent of the study area is located in Travis County, 24% in Burnet, and 21% in Hays, 1.9% in Balanco, and the remaining in Llano. The HU is a transitional area between the two ecoregions of the Edwards Plateau and the Blackland Prairie. The larger western portion is on the plateau, and the smaller eastern portion on the prairie. In the HU, the Colorado River flows through the canyons in the Hill Country region until it issues from the Balcones Escarpment of Austin. Below Austin, the Colorado becomes a slow meandering river. The Highland Lakes, located on the Colorado in the Hill Country region, represent a unique series of reservoirs: Lake Marble Falls, Lake Travis, Lake Austin, and Town Lake. Barton Creek and Onion Creek are its two major tributaries with Barton Springs emerging from the edge of the Edwards Aquifer. The Balcones Canyonlands Refuge is in the central north of the HU. The average rainfall is 28-34 inches per year. The elevation ranges from 250 to 2000 feet. This is a great drop from the plateau to the prairie. The annual temperature is 66-68 °F. The land use/land cover in the HU by area is forest, range, barren land, agriculture, urban/build up land, water and wetland. Ninety-four fish species have been reported to occur in the Colorado River basin (TSNL, 2000).

CHAPTER II

METHODOLOGY

The software programs, ArcGIS® (ESRI), Microsoft Access® and SPSS® (SPSS Inc.), were used in the study. All geospatial data used in the study, unless otherwise stated, were from US Geological Survey (USGS).

Map species known distributions

Sampling data were collected from the following sources:

- Texas Memorial Museum of Science and History (TNHC), University of Texas at Austin;
Texas Commission on Environmental quality (TCEQ);
- Lower Colorado River Authority (LCRA);
- Water Resource Evaluation (WRE), City of Austin;
- Texas Parks and Wildlife Department (TPWD);
- Theses by Tilton, J.E. (1961) and Edwards, R.J. (1976), University of Texas at Austin;
- Division of Fishes, Smithsonian National Museum of Natual History (NMNH);
- Ichthyology collection, The University of Kansas;
- Nonindigenous Aquatic Species Database, USGS;
- Texas Water Commission (TWC);
- Texas Natural Resource Conservation Commission (TNRCC);
- Texas Cooperative Wildlife Collection (TCWC) fish collection, Texas A & M University.

The fish data were compiled and entered into a customized Access relational database, HU8FISH. Each sample had four basic fields: species (may be more than 1 species), locality, time, and collectors. All four fields of information were entered into an entity SAMPLE. The species was linked to the entity SPECIES through an entity CATEGORY. The SPECIES stores the information of classification. The locality was geographically linked to the National Hydrologic Dataset (NHD) in the entity SITE which allowed sampling localities to be graphically displayed. Data were spatially cross-referenced in a tabular format. The georeferencing was processed by overlaying the

Digital Raster Graphics (DRG) with the NHD using ArcGIS. The Hydrologic Unit was used to generate the watershed-wide "known" distribution maps for all species. The 12-digit HU boundary dataset was obtained from Natural Resources Conservation Service (NRCS), USDA The 8-digit HU boundary was created by merging the 12-digit HU dataset. Location description was very general, but allowed plotting either to within 1 mile or within ¼ mile.

<u>Classifying riverine ecosystems into valley segment types</u>

The riverine ecosystems were classified into valley segment types according to Seelbach et al. (1997). Eight hydrogeomorphic variables were used to delineate valley segment types: 1) Stream Size, 2) Size Discrepancy, 3) Floodplain Reach, 4) Relative Gradient, 5) Valley Wall Interaction, 6) Flow, 7) Geology and 8) Land use/land cover.

The pH of the soil was also assigned to each segment as an additional auxiliary factor. The basic procedures for processing Variables 1 through 5 followed those of the Missouri Resource Assessment Partnership (MoRAP, 2002).

The main channel of the Colorado River was assigned the value '4', which is the class of Large River for Variable Stream Size. The Stream Size of all other segments were attributed according to the link number. The Digital Elevation Model (DEM) for Floodpalin was the National Elevation Dataset (NED) files. The classes of Variable Flow of the orginal NHD file, 1 for perenial and 2 for intermmitten segments, were kept. The Geology dataset was classified into five classes: Shale, Limestone/Dolostone, Sandstone, Igneous Rock and Metamorphic Rock. The Land Use/Land Cover data layer was classified on Level I into seven categories in accordance with the Anderson land use codes.

The Valley Segment Types were generated with the combination of the one to eight variables. For predicting purpose, five more additional auxiliary factors were attributed to each segment: Lowland (altitude< 200 meters, Georgieva 2003), Lake, Pool, Gravel pits and Backwater, Sewage, Soil pH, Mouth. The soil data were from NRCS State Soil Geographic (STATSGO) Data Base and the Soil pH variable was classified into three classes: pH > 7, pH close to 7 and pH < 7. The segments with Land Use/Land Cover as water (lulc_code = 5) were assigned the attributes lulcno5 by manually looking at the dominant Land Use/Land Cover of their banks. The values of lulcno5 of other segments were their lulc_code.

Documenting the general habitat affinities or requirements of each species

Habitat descriptions were compiled from Fishes of Missouri (Pflieger 1975), Fishbase (Froese and Pauly 2004), the Fishes of Ohio (Trautman 1981), Freshwater Fishes of Canada (Scott and Crossman 1973), Fishes of Wisconsin (Becker 1983), Fishes of Illinois (Smith 1979), Fishes of Arkansas (Robison 1988), Biota Information System Of New Mexico (BISON, Klingel 2000), USGS Nonindigenous Aquatic Species (NAS, USGS 2004), Fishes Found in the Freshwaters of Texas (1953), Freshwater Fishes of Texas (Chilton 1997) and Atlas of North American Freshwater Fishes (Lee et al. 1980). The pertinent habitat-affinity information was extracted from the compiled descriptions and then documented in a bulleted format.

New habitat-affinity information was also generated from the sampling database in conjunction with the Valley-Segment datalayer. In the study area, all of the valley segments at which a given species has been collected can be selected. A table of the Valley Segment Types was generated in which that species is likely to be found. The habitat-affinity information generated from these procedures was combined with the habitat-affinity information generated from the literature.

Predicting and mapping species distributions

The separate data processed or extracted from the above steps were used to predict and map the potential distribution of all species on a valley-segment by valley-segment basis. The assumption made in this step was that, provided suitable habitat for each species, it has the ability to populate stream segments within the watersheds in which it was known to occur. Two approaches were employed to make predictions of species occurrence. The first used habitat-affinity models and the second logistic regression models.

In the first approach, the habitat-affinity information was used to model valley segment types which provide suitable habitats for each species in the watershed in which they were known to occur. This model was then used to select all the segments in the watershed including those known to occur and known not to occur, and sampled or not sample segments. The model selected the segments predicted to have the species occur within each species' range limits.

Two findings were used to predict the species occurrence. The first was that fish communities and stream habitat were related to bed-rock type. Factors in limestone (carbonate bedrock) streams, such as springs that discharge cool, stable-pH water throughout the year, provide favorable conditions for sensitive fish such as trout. However, valuable limestone farmland commonly is cultivated to the edge of the stream-bank, leaving little or no riparian vegetation, which leads to increased temperature and sedimentation. Although freestone (noncarbonate bedrock) streams generally do not have a supply of cool spring water, riparian vegetation along the stream-banks is favorable for fish habitat. Fish populations were healthier in the three freestone streams than in the four limestone streams surveyed. Poor fish health in limestone streams appears to be caused more by the lack of riparian vegetation than by excess nutrients (Lindsey et al. 1998). The second was that riffles are the most common of turbulent fast water in low gradient (<3%) alluvial channels and are found in plane-bed, pool-riffle, regime, and braided reaches (Hauer and Lamberti 1996, Allen 1995, Hawkins et al. 1993).

The assumptions used to make predictions using the habitat-affinity model were: 1) Streams in the urban areas have little or no riparian vegetation because shading vegetation is usually removed in urbanized areas. In urban areas, aquatic vegetation, which otherwise is a preference for some fish, is not a suitable habitat for them because of degradation resulted from urbanization; 2) Streams draining the forested areas have the best water qulity; 3) No or little riparian vegetation along the banks of the streams in barren areas, and little aquatic vegetation in the water exist because of the non-protected sand or soil particles brought by the runoff or wind. These result in high turbidity, poor sunlight, and not suitable for submerged aquatic vegetation to grow; and 4) The four dams on the Colorado River were considered to prevent the fish from moving or migrating upstream or downstream. Other dams' data from the BASIN of EPA were assumed to be small and not an obstructer of the fish movement in this study.

The habitat affinity information, findings, and assumptions were then used to create a SQL prediction model. In a SQL script, when Size Discrepancy was included for a Size 4 river, Variable Size Discrepancy was replaced with dsize. The dsize is the downstream segment of a stream flowing to.

In the second approach, the backward stepwise logistic regression was used. Variables were assumed to be independent. The requirement for a species to be selected to do the logistic regression model is

$$\min(Ns, Nns) > 27$$

where Ns: number of sampling segments of that species,

Nns: number of non-sampling segments,

min: the smaller number of Ns and Nns when both of them are greater than 27.

This condition was set up to try to get a higher ratio (>= 3:1) of the cases and independent variables. The criteria value for entry into the model denoted by p_E was set to 0.2 and that for removal p_R 0.15 (Hosmer and Lemeshow 1989). The cutpoint probability (c) was determined using sensitivity and specificity plot (Hosmer and Lemeshow 1989). Least square (Wald) backward elimination stepwise logistic regression was used to generate the logistic regression model. The model was not tested for independent data due to the limited sampling data. When a variable caused numerical problems, it was removed from the model. The prediction results using the habitat-affinity and the logistic regression were then compared.

Developing conservation priorities

The conservation indices were made only on the fine-scale of macrohabitat by Valley Segment Type. Two conservation indices, physical conservation index (phyCnsIndx) and biological conservation index (bioCnsIndx), were deveoped in order to identify the conservation sites. The physical conservation index was used to make preliminary site selections based on the macrohabitat quality. Four variables were used to evaluate the macrohabitat quality: Water Quality, Land Use/Land Cover, Road/Railroad Closeness and Dam. The latter two variables reflect the hydrologic alterations. The cell-based screening GIS model of Nonpoint Source Pollution Loads (Adamus and Bergman 1995; Sanders et al. 1996) provided the basis for the water quality analysis. The runoff coefficient (Table 1) and the expected mean concentration (EMC, Table 2) were used in this study according to Adamus and Bergman (1995), Sanders et al. (1996) and Corbitt (1990). Each segment was assigned with pollutant scores by the seven pollutants from 1 (low value) to 5 (high value) using equal interval classification. All pollutant scores for each segment were added together and reclassified to get a water-quality score (scoreWQ) 1-5.

Table 1. The runoff coefficient[1]

LULC code[2]	LULC classes	Soil A[3]	Soil B	Soil C	Soil D
11	Resident	0.28	0.3	0.33	0.36
12	Urban	0.86	0.87	0.89	0.9
2	Agriculture	0.15	0.23	0.32	0.4
3	Range	0.12	0.17	0.23	0.3
4	Forest	0.11	0.14	0.16	0.2
5	Water	1	1	1	1
6	Wetland	0.8	0.8	0.8	0.8
7	Barren	0.16	0.19	0.23	0.3

1. Source: Corbitt (1990), Adamus and Bergman (1995).

2. LULC: Land use / land cover.

3. Soil A, Soil B, Soil C, and Soil D: The hydrologic group for the soil.

Table 2. The expected mean concentration (EMC) of pollutants by land use[1]

ID	Constituent	Urban	Residential	Agriculture	Range	Forest	Water	Wetland	Barren
1	TN(mg/L)	1.57	1.82	4.4	0.7	1.25	0.6	1.1	1.5
2	TP(mg/L)	0.32	0.57	1.3	0.008	0.01	0.003	0.006	0.12
3	BOD(mg/L)	17.2	25.5	4	0.5	0.5	0.1	0.5	0.1
4	Suspended solids (mg/L)	57.9	41	107	1	1	0.5	1	70
5	Total Zinc (ug/L)	141	80	16	6	6	0.5	6	0.6
6	Total Lead (ug/L)	12	9	1.5	5	5	0.5	5	1.52

1. Source: Adamus and Bergman (1995), Sanders et al. (1996) and Corbitt (1990).

For the Land Use/Land Cover estimation, the percentage of each segment in each class of the seven classes (Level I) were calculated. The LULC Classes 1, 2 and 7 were classified based on five scores using natural break. The LULC Classes 3 and 4 combined were classified based on 15 scores (Table 3). The segments with LULC Class 5, which is water, were not assigned LULC values. No segments pass through the wetland (LULC 6) and no LULC values were assigned for it. The sum of the values the five categories was reclassified to obtain the LULC scores (ScoreLULC) (1-5).

Table 3. The LULC scores*

LULC score	Percentage (%)				
	Urban & Residential	Agriculture	Barren	Range	Forest
1	0 5	0 - 7.9	0 - 5	0 - 20	80.01-100
2	5.1-21.1	8 - 24.9	5.1-17	20.01- 40	60.01- 80
3	21.2-37.9	25 43.5	17.1-34.7	0 - 20	60.01- 80
4	38 -57.9	43.6- 67.6	34.8-56.7	40.01- 60	40.01- 60
5	58 -86.2	67.7-100	56.8-100	20.01- 40	40.01- 60
6				0 - 20	40.01- 60
7				60.01- 80	20.01- 40
8				40.01- 60	20.01- 40
9				20.01- 40	20.01- 40
10				0 - 20	20.01- 40
11				80.1 -100	0 20
12				60.01- 80	0 - 20
13				40.01- 60	0 - 20
14				20.1 - 40	0 - 20
15				0 - 20	0 20

* Assumption: Water quality in the Forest areas is the best, Range second, others close.

The score of road/railroad density was calculated by the percentage of the stream segments within the 30-meter buffer area and classified into five categories. The score 1 was attributed to the segments with a dam, and 0 to those without. The dam data were from BASINS (Better Assessment Science Integrating point and Nonpoint Sources) of EPA. The final physical conservation index was calculated by the equation:

$$\text{phyCnsIndx} = \text{scoreWQ} * 2 + \text{ScoreLULC} + \text{road} + \text{Dam} * 2.$$

The biological conservation index was used to calibrate the physical conservation index to represent the biological conditions and refine the selection of the conservation sites. The species richness was estimated by using the total number of species predicted with the habitat-affinities. The species richness was then classified into five categories and assigned scores from 1 to 5. The species of special concern (see Appendix B) include the species endemic to Texas, threatened/endangered, and with state rank from S2 to S4 (no species with state rank S1 occurred). There were two kinds of endemic species. The first was native to the study area, and the other was non-native. The segments having species of the second group received a score of 1, and those having species of the first group 2. For the state-ranked species, the S2 species weighted 2, the S3 species 1, and the S4 0.5. All non-ranked and non-endemic species received a weight of 0. The score of species of special concern was then classified into five classes. The species richness score and the score of species of special concern were then added together to develop the biological conservation index (1-10).

Both the physical index and the biological index were summed (1-15) and reclassified into five categories, this resulted in the conservation indexes. The segments with high conservation indices have higher conservation priorities. The current conservation status was then used to calibrate the ultimate conservation priorities.

CHAPTER III
RESULTS

The valley segment types of the riverine in the HU 12090205

The classification of the stream segments using the eight variables is shown in Figures 4-11. The lower Onion Creek was classified as a small river, while Barton Creek was classified as a creek not as a river (Figure 5). There are seven categories of Size Discrepancy (Figure 6). The streams with high gradient appear in the area where the Edwards Plateau drops down to the Blackland Prairie, west of the Austin urban area (Figure 7). The headwaters on the plateau tend to be steeper. The lower Onion Creek and the lowest Colorado River in the study area are more meanderous than the upper segments of the Colorado River above Austin (Figure 8). The former two flow through the flatter prairie. Most headwaters are intermittent (Figure 9). It was noted that the Onion Creek has intemittent segments below the perennial.

The bedrocks of most of the stream segments are limestone/dolostone (Figure 10). Streams with this type of bedrock receive much of their flow from large springs (Shaffer, 1991). The limestone (calcium carbonate) dissolved in the spring water provides for a stable pH. These factors make the conditions favorable for sensitive fish. Limestone streams are known for naturally low numbers of fish species and high abundances of aquatic plants and invertebrate life (Lindsey et al. 1998).

The segments with floodplain attribute usually are the tributaries of reservoirs (Figure 11). The tributaries of the lower Onion Creek are also part of the floodplain and were located on the freestone (shale, igneous and sandstone) bedrock areas. Freestone streams tend to be fed from runoff; the flow and temperature in these streams is more variable (Lindsey et al. 1998). Freestone streams also do not have as much dissolved calcium as the limestone streams and are vulnerable to changes in pH. Stream segments flow through the urban and agricultural areas in the southeastern study area (Figure 12). Other than this area, more stream segments flow through forest than through range.
The combination of the eight variables generated 136 different types of valley segment in the study area (Figure 13). The other additional auxiliary variables, including Lowland, Pool, Lake, Backwater, Sewage, Spring, soilpH, and Land Use/Land Cover with Water replaced by the bank's LULC of the segments are shown in Figure 14 - 16.

The distribution of the fish in the HU 1209025

The database

Figure 1 shows the entity relationship diagram (ERD) between the entities (tables) of the database of the occurrence of all fish species collected in the study area avaible from the listed sources. These entities shown in Figure 2 are SPECIES, CATEGORY, SAMPLE and SITE. Fields of these entities are defined in Appendix I. Parts of the fields are shown in Figure 2. There were 79 species found in the study area in total, belonging to 19 families. The total number of categories was 2019, representing 335 samples on 100 stream segments.

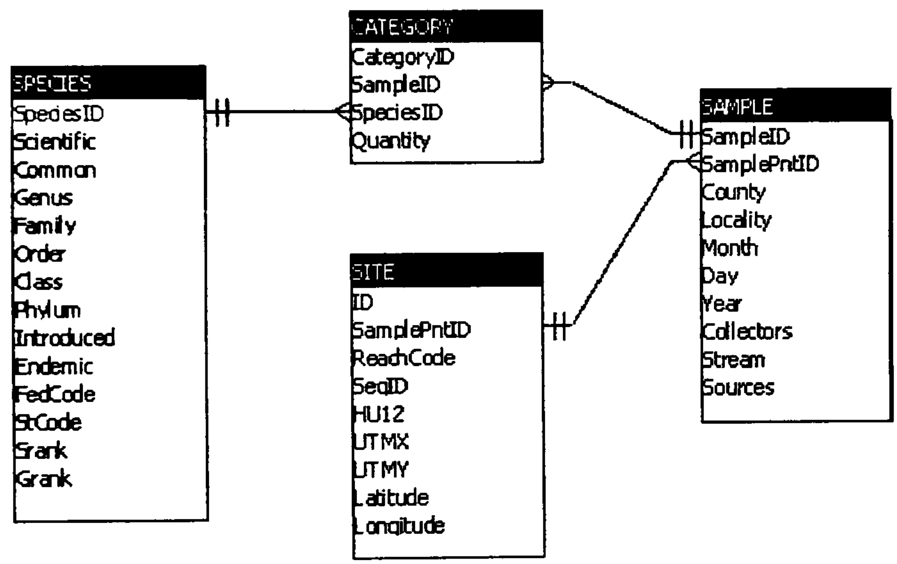

Figure 1. Entity Relationship Diagram (ERD) of the fish database in the Hydrologic Unit 12090205 of Central Texas

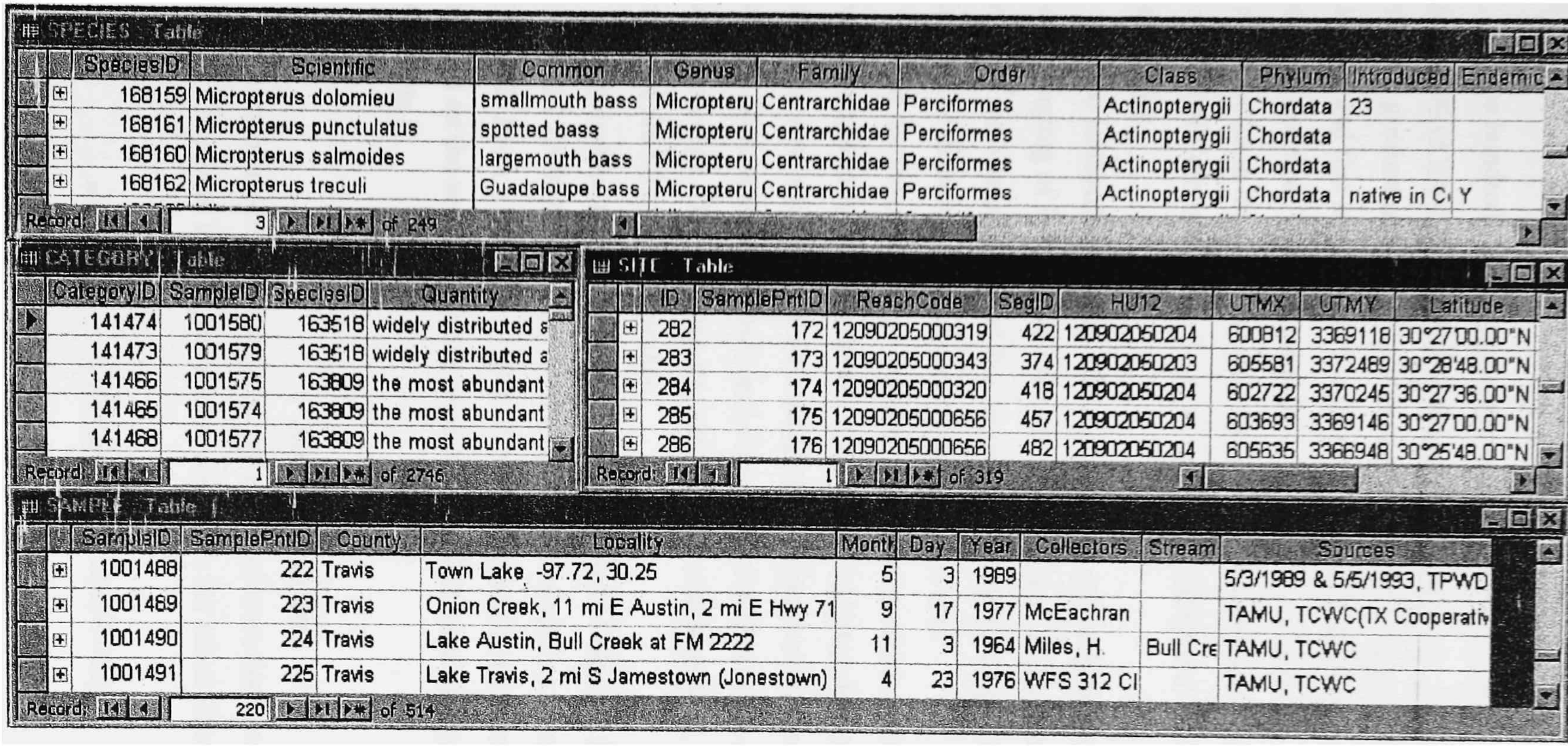

Figure 2. Tables of the fish database in the Texas Hydrologic Unit 12090205

The actual distribution maps

One hundred stream segments were sampled in the study area (Figure 17). Seventy-nine species were collected. The total species number by 12-digit HU (Figure 18) shows that the greatest number of species sampled in the 12-digit HU where the city of Austin is located and that some such 12-digit HUs as in the lower left corners did not have any species sampled. This phenomenon was caused by no effort in these HUs, as no sampling points occur in the sampling map. Most of the samples were collected in the main channel of Colorado River, Barton Creek or Onion Creek. The latter two are the principle tributaries.

The ichthyofauna of the Colorado River is primarily transitional with an intermingling of Eastern and Western forms (Tilton 1961). The HU 12090205 lies on the edge of the Texas Blackland Prairie and the Edwards Plateau. The fish fauna distribution in this HU demonstrates the transitional trends as well.

The southwestern range limits of *Alosa chrysochloris*, *Notropis shumardi*, *Erimyzon sucetta* apparently occur in the HU 12090205. *Scartomyzon congestus*, *Notropis amabilis*, *Notropis buccula*, *Dionda episcopa*, *Campostoma anomalum*, *Micropterus treculi*, *Etheostoma spectabile*, and *Etheostoma lepidum* reach southern and eastern limits in the drainage. Other species are wide ranging and, in general, characteristic of the larger rivers of the Mississippi drainage.

Eighty-four percent of the species of the whole Colorado River Basin were collected in the HU 12090205. The reported total number of species known to occur in the Colorado River basin is 94 (TSNL 1996). The actual distribution of a species was mapped on the same map of the predicted distribution of that species and presented in Appendix C.

<u>Habitat affinities</u>

The habitat affinities compiled and extracted were documented in the bulleted format. They were listed species by species after the actual distribution information.

<u>Predicting species occurrence</u>

The SQL model used for making predictions of species occurrence was presented following the habitat affinities for that species. The predicted distribution of a species was mapped on the same map of the actual distribution of that species and was presented in Appendix C.

Account of species

Carcharhinidae - ground sharks

1) *Carcharhinus isodon* (Valenciennes) - finetooth shark (Figure 19)

Only one finetooth shark was collected in the Colorado in Austin in 1951. No reoccurrence after 1951. Because of its limited occurrence, it is doubtful that a permanent population is present in the river above the estuary region (Tilton 1961).

Habitat:

- Shallow coastal waters close to shore to depths of 32.8 feet (10 m);
- When surface water temperatures drop below 68°F (20°C) finetooth sharks spend the winter months in the waters off the coast;
- Feeds on small bony fishes and cephalopod.

No prediction was made because of its limited occurrence.

Lepisosteidae - gars

2) *Lepisosteus oculatus* (Winchell) - spotted gar (Figure 20)

Spotted gars were collected from five segments of the Colorado River and one segment of its direct tributary.

Habitat:

- Occurs in quiet, clear pools and backwaters of lowland creeks, small to large rivers, oxbow lakes, swamps and sloughs. Occasionally enters brackish waters;
- Less tolerant of turbidity than shortnose gar;

- Typically associated with aquatic vegetation or standing timber in clear water;
- Spawn as early as April, in rapidly flowing water coming from a tract of flooded timber;
- A voracious predator feeding on various kinds of fishes and crustaceans; fry feed on insect larvae and small crustaceans; 90% of adult diet is fish.

Prediction SQL script:

(gradient=1 or (gradient=2 and (lake=1 or pool>0)))
and (lowland=1 or (lowland=0 and lake=1))
and (not lulc_code=7 or (lulc_code=7 and lake=1))
and (not (lulcno5=2 and rocktype=2)) and (not lulc_code=1)

3) *Lepisosteus osseus* (Linnaeus) - longnose gar (Figure 21)

Longnose gars were collected from 20 segments of the Colorado River or its direct tributary.

Habitat:

- Sluggish pools, backwaters, and oxbows along large, moderately clear streams; thrives in man-made impoundments; open water fish: Adults - larger, deeper pools; young - shallow, weedy;
- Spawning upstream movements into smaller and higher gradient streams;
- Appear in most Texas rivers;
- A voracious predator, feeding on various fishes and crustaceans.

Predictions SQL script:

(size >=3 or (size <3 & (mouth=1 or lake=1)))
and (not (lulc=7 or lulc=1)) and
(not (rocktype=2 and lulcNO5=2))

Anguillidae - freshwater eels

4) *Anguilla rostrata* (Lesueur) - American eel (Figure 22)

Three American eels were collected in 2 segments of the Colorado River in 1948 and 1957, respectively. Tom Miller Dam built in 1939 and Longhorn Dam in 1960 undoubtedly restricts the upstream movements of this species.

Habitat:

- Catadromous species;
- Inhabits moderate to large permanent streams, seeking muddy bottoms and still waters; Extremely tolerant to turbid waters;
- During daylight hours it is found in deep pools about logs, boulders, or other cover.

Predictions SQL script:

size > 1 and belowLonghornDam=1

The Longhorn Dam was completed in 1960. The samples were taken before the completion of the Dam.

Clupeidae - herrings & shads

5) *Alosa chrysochloris* (Rafinesque) - skipjack herring (Figure 23)

The collection records of the skipjack herring were from the Colorado River in 1942 and 1958. The occurrence reason might be correlated with the unusually high volume of flow in the two years (Tilton 1961)

Habitat:

- Open waters of large rivers, often congregates in large numbers in the swift currents below dams; unable to get upstream either over or around the dams;
- migrate both upstream and downstream in rivers;
- Common in turbid river, the Mississippi;
- More common if the channel deepened and turbidity reduced.

Predictions SQL script:

size>2 and belowLonghornDam=1

The herring was collected from the segments above Longhorn Dam before the dam completed.

6) *Dorosoma cepedianum* (Lesueur) - gizzard shad (Figure 24)

The gizzard shad is abundant, mainly found in the Colorado River and its direct tributaries. Fourty-seven segments were recorded to have this species occur. It is the most abundant species outside the family Cyprinidae (Tilton 1961).

Habitat:

- In Texas found in all major streams and reservoirs;
- Most abundant in reservoirs and large rivers; a variety of quiet-water habitats, including natural lowland lakes and ponds, man-made impoundments, and the pools and backwaters of streams;
- Occurs in both extremely clear and extremely turbid waters, but prefers those where fertility and productivity are high;
- Avoids very small high gradient creeks and those that lack large, permanent pools;
- Spawn in late spring, in shallow protected water;
- Adhesive eggs attach to submerged objects;
- A herbivorous filter-feeder almost entirely.

Predictions SQL script:

lake=1 or ((size>=3 and (gradient<3 or (gradient=3 and (lake=1 or backwater>0 or mouth=1 or valw_3c>1)))) or (size<3 and dsize=4 and (mouth=1 or floodp_cd=1 or backwater>0))) and not (size=3 and lulc_code=7)

7) *Dorosoma petenense* (Günther) - threadfin shad (Figure 25)

The threadfin shad is less abundant. It was also found in 28 segments in the Colorado River and its direct tributaries.

Habitat:

- Pelagic, plankton-feeding, filter-feeders;

- Rivers, reservoirs, moderate to large streams, rare in moderate and small streams; rippling the surface; usually found in the upper five feet of water;
- Sensitive to temperature, die-offs below 45 °F (7.2 °C); more found in a noticeable current; others similar to Gizzard shad;
- In Texas, common in all east Texas streams and introduced as a forage fish in many reservoirs statewide (was not found in the TPWD's stocking history);
- Spawn in the spring when water temp reach approx. 70F (21C) and may continue into the summer; spawn over plants and other objects, or under brush and logs.

Prediction SQL script:

size>2 or (size<=2 and dsize=4 and
(lake=1 or pool>0 or backwater>0 or mouth=1))

Cyprinidae - minnows & carps

8) *Campostoma anomalum* (Rafinesque) - central stoneroller (Figure 26)

The central stoneroller was found in 25 segments, mostly in creeks. Some specimen were collected in other sizes of streams and rivers.

Habitat:

- Abundant in small, clear upland streams;
- Small, clear streams with moderate to high gradient, well-degined gravel, rubble or bedrock riffles, and permanent flow; occasionally in medium to large-size rivers;
- Riffles, short rocky pools where riffles and pools alternative in rapid succession. more tolerant of high turbidity than the largescale stoneroller;
- Tolerant of turbid, silty waters;
- Spawn in small streams of moderate and high gradients having sandy-gravel bottoms breeding individuals often found in pools adjacent to riffles.

Prediction SQL script:

size<4 and (gradient>1 or (gradient=1 and (lowland=0 or size>1))) and lake=0
and (not (rocktype=2 and lulc_code=2)) and (flow=1 or (flow=2 and pool>0))

The three segments where this species was actually taken were not predicted use the habitat-affinity model. They were probably occasional cases.

9) *Cyprinella lutrensis* (Baird & Girard) - red shiner (Figure 27)

The red shiner was taken from 16 segments. More segments of creeks or headwaters than that of rivers.

Habitat:

- Sluggish low-gradient habitats, especially backwaters as well as riffle, creek mouths and medium-sized streams over a wide variety of bottom types;
- Uncommon or absent in clear, high-gradient streams; avoids waters that are continuously clear or cool;
- Tolerant of high turbidityies and siltation;
- Replaced in the clear lowland tributaries of the large silty rivers by N. venustus;
- Abundant in the relatively unstable streams of prairie and heavily farmed regions;
- Range throughout Texas (a plains species);
- Spawn over an extended period of time from spring into fall months; spawn may occur on riffles, on or near submerged objects, over vegetation beds or in association with sunfish nests;
- Feed on small invertebrates.

Prediction SQL script:

```
(gradient=1 or (gradient>1 and  lowland=1 )) and
(not lulc_code=4 or (lulc_code=4 and
(gravelpits>0 or mouth=1 or pool>0)))
```

10) *Cyprinella venusta* Girard - blacktail shiner (Figure 28)

The blacktail shiner was collected from 44 segments all over the drainage. It was the most abundatn species in the Colorado River according to Tilton (1961). In the study drainage it is less frequent than some sunfishes and largemouth bass.

Habitat:

- Most common in sandy pools and runs of small to medium rivers; also occurs in creeks and rocky pools and runs; upland populations occur over substrates with more gravel and rubble;
- Prefer flowing waters (unlike golden shiner); most abundant in areas with little vegetation, swift current, and gravelly bottoms;
- Even though it prefers some current, it is also found in some upper valley impoundments; occurs in moderately clear to very turbid waters;
  Abundant, particularly in LA and TX, where often is numerically dominant species;
- In Texas, unknown in the Panhandle; primarily found from the Edwards Plateau eastward.

Prediction SQL script:

(lowland=0 and (gradient=1 or (gradient=2 and (pool>0 or lake=1)) or (gradient=3 and (lulc_code=3)))) or (lowland=1 and (gradient>1 or (gradient=1 and (not (lulc_code=4 or lulc_code=1 or lulc_code=7) or ((lulc_code=4 or lulc_code=1) and (spring=1 or (size>1 and (pool>0) or (size=1 and mouth=1))))))))

11) *Dionda episcopa* Girard - roundnose minnow (Figure 29)

The roundnose minnow occurred only in 3 segments. This minnow is typically a fish of the clear spring areas west of the lower Colorado drainage, its population in the larger, more turbid river, is limited (Tilton 1961).

Habitat:

- Inhabits rocky pools, sometimes runs, of headwaters, creeks and small rivers;
- Often abundant in shallow, vegetated pools of clear, low gradient rivers and creeks;
- Often among filamentous algae;
- mass spawning occurred in about 25mm of water (17-18C); eggs heavy but nonadhesive, lodging in gravel of spring;

Prediction SQL script:

size<4 and gradient=1 and pool>0 and 2<lulcno5<7

and (not (rocktype=2 and lulcNO5=2))

12) *Hybopsis amnis* (Hubbs & Greene) - pallid shiner (Figure 30)

The pallid shiner was found in 4 segments only. The number was limited but it apparently ranges throughout the drainage (Tilton 1961).

Habitat:

- Essentially a lowland species, also occurs in sluggish streams draining level uplands;
- Inhabits sandy and silty pools of streams medium to large rivers; and quiet waters over sand-silty bottoms, often at end of sand and gravel bars; also common in some reservoirs and oxbow lakes;
- Intolerant of heavy siltation and pollutants;
- Breeds late winter and early spring in south;
- Populations greatly reduced or exterminated in northern parts of range.

Prediction SQL script:

(size>2 or (size<=2 and pool>0 and flow=1)) and

(gradient=1 or lake=1) and

(not (rocktype=2 and lulcno5=2))

13) *Lythrurus fumeus* (Evermann) - ribbon shiner (Figure 31)

The ribbon shiner was taken from 3 segments.

Habitat:

- small to medium-sized lowland streams with low gradient;
- Occurs in quiet, usually turbid, mud-bottomed or sand-bottomed pools of headwaters, creeks and small rivers and bottom materials of sand and silt or clay;
- tolerant of turbidity and associated ecological factors; characteristic of creeks and ditches flowing through agricultural areas; locally common, perhaps increasing in abundance and distribution in agricultural regions.

Prediction SQL script:

lowland=1 and gradient=1

14) *Lythrurus umbratilis* (Girard) - redfin shiner (Figure 32)

The redfin shiner was found only recently in 1994 in one segment of Onion Creek close to the Colorado River. Its west ranges recorded is San Jacinto (Lee et al. 1980).

- Relatively clear, warm water + absence of strong current (low-gradient creeks);
- Prairie Region: permanent pools of rocky or gravelly creeks having high gradient and low or intermittent flow;
- Lowlands: ditches having little current and an abundance of submerged aquatic vegetation, and small, high-gradient creeks;
- Along the cool, spring-fed streams of Plateaua, weedy backwaters and overflow pools;
- Associates with sunfish for spawning.

Prediction SQL script:

(not (lulc_code =2 and rocktype =2)) and lulc_code >1 and

((flow=1 and gradient<3) or (flow=2 and gradient>1 and pool>0)) and lowland=1

15) *Macrhybopsis aestivalis* (Girard) - speckled chub (Figure 33)

The speckled chub was found in 3 segments of different sizes. This is different from the descriptions by Tilton (1961) that it was found in all segments of the main river but not taken from the tributaries.

Habitat:

- Inhabits sand and gravel runs of small to large rivers with low gradient over fine gravel or sand;
- All segments of the main river but was not taken from the tributaries. Collected only from swift to very swift current over sand bottom in the main river channel;
- Occurs in streams with continuous high turbidity as well as those that are moderately clear.

Prediction SQL script:

gradient=1 & size=4 & not (rocktype=2 & lulcno5=2)

16) *Notemigonus crysoleucas* (Mitchill) - golden shiner (Figure 34)

The golden shiner was collected from 20 segments of different sizes of streams. It was probably released as a bait (Tilton 1961).

Habitat:

- Quiet water, rare in noticeable current; slough, pond, lake, stream and ditch of low-gradient, and the permanent pools of intermittent upland creeks;
- Tolerant of moderate turbidity, but thrives in clear, heavily vegetated habitats;
- In Texas ubiquitous; native only to east Texas streams;
- Spawn in the spring when water temperature exceed 70F, ceases when temp exceed 80F, no nest; adhesive eggs scattered over algae or submerged vegetation;
- Omnivorous; half plant, half animal; surface and midwater feeder.

Prediction SQL script:

(gradient=1 or (gradient>1 and (lake=1 or pool>0 or

backwater>0 or mouth=1 or gravelpits>0))) and (flow=1 or

(flow=2 and lowland=0 and (pool>0 or mouth=1))) and (not lulc_code=1/7 or

(lulc_code=1/7 and (valw3c>1 or pool>0 or lake=1)))

17) *Notropis amabilis* (Girard) - Texas shiner (Figure 35)

The Texas shiner was found in 5 segments of the main river, Onion Creek and small creeks both the Plateau and the Prairie. It abounds in the smaller streams in the upper Colorado drainage, but is not considered an integral part of the typical Colorado River (Tilton 1961).

Habitat:

- Very common in springs and headwater tributaries, where may be , sometimes limited numbers in larger streams;

- Occurs in clear water, abundant in streams with significant spring-flow components in streams with moderately fast currents;
- One of the most common inhabitants of Edwards Plateau streams;
- In pools below riffle areas, the swiftly moving waters along gravel bars and in moderately flowing pool, in areas below low-water dams and road crossings where there is turbulent water flow creating eddy habitats;
- Predaceous; the large eyes are an adaptation for sight feeding in swift water.

Prediction SQL script:

((spring = 1) or pool > 0 or belowdam=1) and (not (lulcno5 = 2 and rocktype = 2)) and (not lulcno5 = 7 or lulc_code =1)

18) *Notropis buccula* Cross - smalleye shiner (Figure 36)

The smalleye shiner was found only in two segments of the main river. Its native range is the upper 2/3 of Brazos River drainage, but is apparently introduced into adjacent Colorado River drainage (Lee et al. 1980). The specimens were collected in 1951 before the Longhorn Dam (Town Lake) was built (1961).

Habitat:

- Texas prairie streams;
- Typically in turbid waters of broad, sandy channels of main stream;
- Preferred habitat includes fairly shallow water (38 to 82 centimeters (15 to 32 in) in depth) in broad, open sandy channels with a moderate current;
- Ostrand (2000) found abiotic factors associated with smalleye shiner habitat to include specific conductance < 30 mS, relatively high current velocity (> 0.20 m/s) (0.65 feet/s) and high turbidity (> 41 NTU);
- Within their preferred habitat, smalleye shiners are most often found using the center of the channel, avoiding the shallow depth and slow velocity of the stream edges (Moss and Mayes 1993).

Prediction SQL script:

size >1 and (lake =0 or (lake=1 and belowdam=1)) and (gradient >1 or (gradient=1 and size=4)) and (not (lulcno5 = 2 and rocktype = 2)) and (not (lulcno5 = 4 or lulcno5 = 6)) and lowland=1

19) *Notropis oxyrhynchus* Hubbs & Bonham - sharpnose shiner (Figure 37)

There was only one collection of the sharpnose shiner in the lower main river. This species is endemic to the Brazos River drainage. It was apparently introduced into the Colorado River drainage (Lee et al. 1980).

Habitat:

- Endemic to Brazos River drainage, tx, where appears to be generally distributed throughout main river;
- Inhabits sand and gravel runs of medium to large rivers;
- Less often found in sand or mud bottomed pools;
- Brazos River typically a rather large turbid river, with bottom a combination of sand, gravel and clay-mud;
- Found at reservoirs in the study area.

Prediction SQL:

(size=3 or size=4) and valw3c < 3

20) *Notropis shumardi* (Girard) - silverband shiner (Figure 38)

The silverband shiner was taken in 3 segments. It is closely confined to large rivers which are very turbid and have substrrate that is mixture of sand, gravel, silt and mud (Lee et al. 1980).

Habitat:

- Moderate or strong current over a bottom of sand or fine gravel;
- Closely confined to large rivers, penertrate rarely into the lower sections of tributaries;
- Tolerant for extremely turbid conditions.

Prediction SQL script:

size=4 or (size<4 and (dsize=4 and (lake=1 or mouth=1)))

21) *Notropis stramineus* Cope - Sand shiner (Figure 39)

The sand shiner was found in 6 segments of the main river and its direct tributary.

Habitat:

- Occurs throughout the Prairie Region; rare in upland areas;
- Strong affinity for sandy bottoms;
- Streams of all sizes but is seldom abundant in the largest rivers. It is replaced towards the headwaters of many prairie streams by the bigmouth bottoms;
- Most abundant in the shallow, sandy pools of medium-sized creeks having permanent flow, moderately clear water, and low or moderate gradient.

Prediction SQL script:

(pool > 0 or lake = 1) and lowland =1 and (flow = 1 or (flow = 2 and (sdiscr_11c = 3 or sdiscr_11c = 6 or sdiscr_11c = 8))) and (not (rocktype = 2 and lulcno5 = 2))

22) *Notropis texanus* (Girard) - weed shiner (Figure 40)

Weed shiners were collected from 21 segments of creeks and rivers. Except one segment, all 20 segments are in the lower part of the drainage.

Habitat:

- Lowland;
- Large ditches and lowland rivers having noticeable current (or slow current, or without current), a sandy bottom, and little or no aquatic vegetation (or associated with emergent vegetation in shoal areas);
- Penetrates the lower reaches upland streams;
- Small to large, low-gradient streams.

Prediction SQL script:

lowland = 1 and (gradient = 1 or (gradient > 1 and
(lake = 1 or pool > 0 or gravelpits > 0 or
mouth = 1 or backwater > 0)))

23) *Notropis volucellus* (Cope) - mimic shiner (Figure 41)

The mimic shiner was taken from 5 segments of the main river and its close tributaries .

Habitat:

- clear streams ranging in size from medium-sized creeks to rather large rivers;
- also occurs in quiet areas of lakes;
- most abundantly near riffles in noticeable current.

Prediction SQL script:

(gradient = 1 or (gradient > 1 and (pool = 1 or lake = 1))) and
(size > 1 or (size = 1 and pool = 1)) and (not (lulc_code = 1)) and
(not (lulcno5 = 2 and rocktype = 2))

24) *Opsopoeodus emiliae* Hay - pugnose minnow (Figure 42)

The pugnose minnow was found in 8 segments of the main river and its direct tributaries in the lower part of the drainage.

Habitat:

- Inhabits clear to turbid vegetated lakes, swamps, oxbows and sluggish streams of all sizes;
- Found in natural lakes, sloughs, borrow pits, and sluggish Lowland ditches;
- Over mud and sand or debris substrates.

Prediction SQL script:

(((gradient = 1 or dsize =4) and lowland = 1) or
(size = 4 and abvdamlong = 1)) and
(not (lulc_code = 1 or lulc_code = 7))

25) *Phenacobius mirabilis* (Girard) - suckermouth minnow (Figure 43)

The suckermouth minnow was found in only one segment of the main river in 1954 before the Longhorn Dam was built. Hubbs and Hettler (1959) reported this species as present in almost all collections made during 1954 and 1959 but absent in Austin after the latter date. However, the Tilton's (1961) 1957 and 1958 collections for this study indicate that this species is still present in the lower river.

Habitat:

- Riffle (low to moderate gradient, small to mid-sized streams; fast turbulent water);
- Avoids those with intermittent flow or continuously cool water.

Prediction SQL script:

gradient < 3 and lake=0 and flow=1 and belowdam=0

26) *Pimephales promelas* Rafinesque - fathead minnow (Figure 44)

Fathead minnows were collected from 8 segments of headwaters, creeks and rivers.

Habitat:

- Muddy pools of headwaters, creeks and small rivers; Favor sluggish streams, backwaters, ditches, and ponds over soft mud bottom;
- Found from clear to turbid streams; Tolerates unsuitable conditions (e.g., turbid, hot, poorly oxygenated, intermittent streams);
- Most abundant in small streams where competition with other species is limited;
- School in midwater or near the bottom;
- Eggs deposited over submerged objects and guarded by males;
- Feed primarily on plant material; invertebrates are sometimes consumed.

Prediction SQL script:

(pool>0 or lake=1 or gradient=1) and (lucno5=7 or lulcno5=3)

27) *Pimephales vigilax* (Baird & Girard) - bullhead minnow (Figure 45)

In the 18 segments where the bullhead minnow, 17 are of the main river or its direct tributaries. Tilton (1961) reported it as very widely distributed and abundant in the Colorado River below Austin.

Habitat:

- Sluggish pools and backwaters of medium-sized to large streams;
  Continuous flow and low to moderate gradients;
- Avoids strong current (both strong current channel and quiet backwaters);
  Fairly tolerant of turbidity and siltation;
- Feed mostly on bottom dwelling aquatic insects.

Prediction SQL script:

(flow = 1 or (flow = 2 and dsize = 4)) and ((size = 2 and pool > 0 and gradient = 1) or (size <3 and dsize = 4) or (size = 3 and gradient <3) or size = 4)

28) *Carassius auratus* (Linnaeus) - Goldfish (Figure 46)

The goldfish was recorded only in 2 segments of Barton Creek and Waller Creek in 1961 and 1975. Edwards (1975) reported that it was stocked at the Biology Ponds on campus of the UT Austin. Its occurrences are often sporadic although well established at some North American localities since its introduction from Eurasia, and this may reflect continued releases and escapements rather than established populations (Lee et al. 1980).

Habitat:

- Quiet pools, submerged vegetation, tolerate turbidity and high organic content;
- Common in sluggish streams and in the lakes and lagoons of urban centers, inhabits shallow water with dense vegetation in warm lakes, reservoirs, rivers and quiet streams;
- Compared to common carp, less tolerant to moderate or high gradients, cool water, great turbidity, and rapid siltation, domestic and industrial pollutants;
- Eggs released at depths of 15cm over submerged aquatic plants or willow roots;
- The increase in the population size is not because optimal habitat for the species has

increased but rather because there are extensive areas where most other fishes have been eliminated, and the ecologically tolerant goldfish thus has little competition.

Prediction SQL script:

(gradient =1 or (gradient = 2 and pool > 0 or lake = 1 or gravelpits > 0 or valw_3c > 1)) and not lulcno5 = 7 and (lulcno5 =1 or lulcno5 =2 or sewage >0) and (size =4 or (size < 4 and (sdiscr_11c =3 or sdiscr_11c =6 or sdiscr_11c =8)))

29) *Cyprinus carpio* Linnaeus - common carp (Figure 47)

Like the goldfish, common carp is not a native species of North America. However, it is more successful. It was collected in 32 segments from 1961 to 1998.

Habitat:

- Hardy and tolerant of a wide variety of conditions but generally favor large water bodies that are highly productive as a result of natural fertility, runoff from heavily fertilized farmlands, or organic pollutants;
- Least abundant in clear, high-gradient streams of pleteaus, but even here are locally abundant in warm backwaters and in streams polluted by organic wastes;
- In streams adults are most often found in the deeper pools around piles of drift, logs, or other submerged cover. In large lakes and reservoirs this fish is occasionally taken at depths of nearly 100 ft, but is more characteristic of shallow waters along the shore;
- Laying sticky eggs in shallow vegetation;
- Omnivorous; adults uproot and destroy submerged aquatic vegetation and therefore may be detrimental to duck and native fish populations;
- In Texas, found statewide.

Prediction SQL script:

(((lowland =0 and gradient < 3) or lowland = 1) and size <3 and (pool > 0 or lake = 1 or gravelpits > 0 or mouth = 1 or backwater > 0) and lulc_code <7) or size >=3

Catostomidae - suckers

30) *Carpiodes carpio* (Rafinesque) - river carpsucker (Figure 48)

All of the 15 segments where the river carpsucker are of the main river or its direct tributaries above Longhorn Dam, indicating that this species prefer slow to moderate current in open waters. Tilton (1961) reported that this species was more common in the lower river.

Habitat:

- Occurs in lakes and pools and backwaters of creeks and small to large rivers;
- Abundant in quiet, silt-bottomed pools of rivers;
- Low to moderate gradients, frequently in impoundments;
- Prefer waters that are turbid much of the time and is replaced in clearer waters by the quillback or highfin carpsucker;
- Spawn among the submerged portions of trees and brush and/or while the river was in flood;
- Main center: prairie region; tending to avoid the moutainous regions of the state.

Prediction SQL script:

```
(pool>0 or backwater>0 or gravelpits>0 or sidepond>0 or lake=1 or mouth=1) and
((size>2 and (valw_3c>1 or gradient=1)) or
(size<=2 and (dsize=3 or dsize=4)))
```

31) *Erimyzon sucetta* (Lacepede) - lake chubsucker (Figure 49)

Only one segment at the mouth of Shoal Creek in the main river was reported as having the lake chubsucker.

Habitat:

- lowland;
- sluggish;
- clear & aquatic vegetation.

Prediction SQL script:

lowland=1 and gradient=1 or ((gradient =2 or gradient=3) and (lake=1 or pool>0) and sewage=0 and lulc_code > 1 and (not (lulc_code = 7)) and (not (lulc_code =2 and rocktype = 2))

32) *Ictiobus bubalus* (Rafinesque) - smallmouth buffalo (Figure 50)

All of the 17 segments where the smallmouth buffalo was taken are in the reservoir or are the first tributaries above Longhorn Dam. Tilton (1961) collected this species below Travis in the Feyette county.

Habitat:

- Large streams and rivers; common in waters with modest current; prefers slightly clearer water than the bigmouth buffalo and is found less often in strong current than the black buffalo;
- Occasionally in lakes and medium-sized rivers; firm-bottomed channels, sometimes in backwaters and in mouths of tributaries;
- Spawn in the spring when water temp reach 60-65 °F, eggs are broadcast over weeds and mud bottom;
- Feeds on shellfish and algae;
- In Texas found in most large streams, rivers and reservoirs exclusive of the Panhandle.

Prediction SQL script:

size = 4 or (size < 4 and dsize = 4) and (not (lulc_code = 1 or lulc_code = 1)) and (not (rocktype = 2 and lulcno5 = 2))

33) *Scartomyzon congestus* (Baird & Girard) - gray redhorse (Figure 51)

The gray redhorse was collected from 26 segments of all sizes of streams. It is a fish of the clear-water streams and confined to the upper river segment of the Colorado drainage (Blair 1950).

Habitat:

- Low gradient streams;

- Adults most often occupy medium to large pools, with cobble, gravel, silt, or sand bottoms; juveniles and young often in riffles and gravelly runs, usually avoid densely vegetated areas;
- Clear to moderately turbid, warm, sluggish;
- Specimens most often from pools with silty bottoms.

Predction SQL script:

(gradient<2 or (gradient>=2 and (Pool > 0 or mouth=1or valw_3c<3)))
and (flow=1 or (flow=2 and mouth=1))

Characidae - characins

34) *Astyanax fasciatus* (Cuvier) - Banded astyanax (Figure 52)

Found only in 4 segments, the introduced banded astyanax was restricted in Travis county (Tilton 1961). No specimen were collected after 1961.

Habitat:

- Inhabits streams and rivers without strong currents and lentic areas;
- Its restriction to the Travis County may be correlated with its requirements for warmer temperatures during winter or with its recent introduction;
- Associated with moving clear waters and a gravel bottom;
- Vivacious, eats small fish.

Prediction SQL script:

AbvDamTomM=0 and spring=0 and not (rocktype=2 and lulcno5=2)
and not lulcno5=7 and (gradient>1 or (gradient=1 and lake=1))

35) *Astyanax mexicanus* (Filippi) - Mexican tetra (Figure 53)

The Mexican tetra, an introduced species, was confined to segments between Mansfield Dam and Tom Miller Dam and close to Barton Springs. It were collected from 7 segments.

Habitat:

- Established in Edwards Plateau Region in central Texas, particularly abundant in constant temperature springs and their outflows (introduced to Colorado River);
- A variety of habitats; tends to school in pools and below swift areas in eddies; young of-the-year have been observed in shallow water near overhanging bank vegetation
- Associated with shore vegetation and leaf litter;
- In TX, migrated seasonally to escape low winter water temperatures;
- Feeds on insects, crustaceans and worms; populations in northeastern Mexico are omnivorous, with higher plant remains filamentous algae and aquatic insects comprising bulk of diet;
- Degradation of stream habitats resulting from overgrazing, siltation, channelization, and water diversion are probable reasons for the decline of the species.

PredictionSQL script:

(spring = 1 or (right below the dams)) or (pool > 0 or lake = 1 or sdiscr11c = 3) or sdiscr11c = 6 or sdiscr11c = 8) and (not (lulcno5 = 7)) and (not (lulcno5 = 2 and rocktype = 2))

Ictaluridae - bullhead catfishes

36) *Ameiurus melas* (Rafinesque) - black bullhead (Figure 54)

The black bullhead was found in 9 segments of all sizes from 1947 to 1998.

Habitat:

- Highly tolerant of many types of industrial and domestic pollutants, turbid water, and warm waters;
- Silt bottom, no noticeable current or strong flow, and a lack of diversity in the fish fauna;
- Prefer the permanent pools of small, intermittent creeks and the muddy oxbows and backwaters of large streams in the prairie region;

- The largest popl occur in base and low-gradient portions of small and moderate sized streams; in the impoundments, backwaters, oxbows, and overflow ponds, particularly along the larger riers; in quarries and farm ponds;
- Incapable of invading in the deeper, cooler, clearer waters, with or without some vegetation, which is the habitat of the brown bullhead, or the very clear water, heavily vegetated habitat of the yellow bullhead;
- Nest: excavate nests in mud bottoms; prefer some sort of cover;
- Omnivorous; nocturnal feeder.

Prediction SQL script:

((gradient=1 or (size=4 and valw_3c>1)) and flow=1)

or (gradient>1 and flow=2 and (gravelpits>0 or lake=1 or pool>0 or valw_3c>1))

or (lulc_code=1 and gradient=1)

37) *Ameiurus natalis* (Lesueur) - yellow bullhead (Figure 55)

The black bullhead was found in 9 segments of all sizes from 1961 to 1998.

Habitat:

- Permanent flow;
- Avoid strong currents (pools, backwaters, and sluggish current);
- In plateau areas, heavily vegetated; elsewhere, open pools;
- Found throughout Texas except the Trans-Pecos and Panhandle.

Prediction SQL script:

flow=1 and (gradient=1 or (gradient>1 and

(pool>0 or lake=1 or valw3c>2 or floodpln=1))) and

(lowland=0 & (lulcNO5=4,3)) or (lowland=1)

38) *Ictalurus furcatus* (Lesueur) - blue catfish (Figure 56)

Among the 13 segments where the blue catfish was found, more segments were in the main channel or its direct tributaries. Tilton (1961) reported that no individuals were taken above Colorado County. The blue catfish occurring in the study area may due to the stock because the specimen were collected from 1985.

Habitat:

- Medium to large rivers and principal tributaries;
- Sandy, avoid silted bottom;
- Prefers clear, strongly flowing water;
- In Texas it is absent from the northwestern portions of the state including the Panhandle, but present elsewhere in larger rivers.

Prediction SQL script:

(size = 4 or (size > 1 and (sdiscr_11c = 3 or sdiscr_11c = 6 or sdiscr_11c =8)))

and (not (rocktype = 2 and lulc_code = 2))

39) *Ictalurus punctatus* (Rafinesque) - channel catfish (Figure 57)

Widely distributed, the channel catfish was taken from 39 segments of all sizes. More segments are in the main river and its tributaries.

Habitat:

- Large streams having low or moderate gradients;
- Adults found in large pools, in deep water or about submerged logs and other cover, young in riffles or the shallower parts of pools;
- Extremely adaptable, basically it is a stream fish, do well in farm pond, reservoir, stream and river;
- Prefers clean, well oxygenated water, but also in ponds and reservoirs;
- Range throughout Texas.

Prediction SQL script:

(((size > 1 and gradient < 3 and (lulc_code > 1 and lulc_code < 7))) or ((size = 1 or gradient = 3 or lulc_code = 1 or lulc_code = 7) and (lake = 1 or valw_3c > 1 or pool > 0 or backwater > 0 or mouth = 1 or floodp_cd = 1))) and (not (rocktype = 2 and lulcno5 = 2))

40) *Pylodictis olivaris* (Rafinesque, 1818) - Flathead catfish (Figure 58)

All of the specimens of the flathead catfish were taken from 25 segments of the main river or its tributaries. Tilton (1961) noted that it apparently prefers the deep sections of the main river channel.

Habitat:

- Large streams, rivers and their principal tributaries of the prairie, and in the larger ditches of the lowlands, in plateau areas restricted to reservoirs and the downstream sections of the largest streams;
- A variety of stream types but avoids high gradients or intermittent flow; young among rocks on riffles; adults - pools, near submerged logs, piles of drift, or other cover;
- Tolerates turbid;
- Nest: Males construct nests by excavating a shallow depression in a natural cavity;
- Occur statewide in Texas.

Prediction SQL script:

(size > 2 or (size <= 2 and dsize = 4)) and

(gradient = 1 or (gradient >1 and (lake = 1 or pool > 0 or backwater > 0 or mouth = 1)))

Esocidae - pikes & pickerels

41) *Esox lucius* Linnaeus - northern pike (Figure 59)

The northern pike was recorded only once by Edwards (1975) in the segment at the mouth of Waller Creek. This was an introduced species and might have survived only little time after the introduction as no specimen were collected after 1975.

Habitat:

- Water temp < 85°F (29.44 °C), good growth 10-23 °C, optimal 19-21 °C; reaches below Mansfield Dam, or headwaters not in Urban areas;

- pH 5-9.5;
- Heavy vegetation along shorelines (considerable aquatic and flooded land vegetation);
- Relatively quiet water, bays, marshes and pools of low-gradient streams, clear water;
- Natural lakes, reservoirs, and large streams and rivers;
- Spawn in marsh habitats in Spring, feed in the shallow littoral zone of lakes and reservoirs to feed in Summer.

Prediction SQL script:

(size = 4 and gradient <3) or (dsize_code=4 and (pool = 1 or lake = 1 or floodpln = 1 or mouth = 1)) and (sdiscr_11c = 0 or sdiscr_11c = 1) and (not lulcno5 = 1) and (not lulcno5 = 7) and (not lulcno5 = 2 and rocktype = 2)

Atherinidae - silversides

42) *Menidia beryllina* (Cope) - inland silverside (Figure 60)

Almost all of the segments where the inland silverside were collected are the main channel or its direct tributaries. Specimens were taken from 1975-1997.

Habitat:

- A marine species that ascends rivers. Some landlocked populations, many of which have been established in impoundments;
- Inhabits the large rivers; also stocked in some large reservoirs;
- Abounds in large rivers in reservoirs;
- Found in moderate current along sandbars adjacent to the main channel. It is readily collected in the habitat at all times of the year;
- Prefered spawning site-Lake Texoma; eggs laid in algae associated with emergent vegetation;
- Surface or littoral feeder;
- Found in many TX reservoirs.

Prediction SQL script:

(size = 4 or (size < 4 and (dsize = 4))) and

(gradient = 1 or (gradient > 1 and (valw_3c > 1 or lake = 1 or mouth = 1 or pool = 1)))

and (not (lulc_code = 1)) and (not (lulcno5 = 2 and rocktype = 2))

Fundulidae - topminnows

43) *Fundulus notatus* (Rafinesque) - blackstripe topminnow (Figure 61)

Twelve of the 13 segments where the blackstripe topminnow was found are the main channel or its tributaries. All of the 13 segments are in the lower part of the drainage.

Habitat:

- Prefer slightly warmer and more turbid waters than the blackspotted toopminnow, but otherwise their habitats are not notably different;
- The blackstipe topminnow is most often found along large lowland rivers and in the pools of streams draining undissected uplands;
- Low-gradient; prefers the slow-moving, quiet backwaters and pool margins;
- In smaller numers in some clearer upland streams. and can be found over a variety of bottom types;
- Surface feeder, terrestrial insects and algae.

Prediction SQL script:

(lowland = 1 or (lowland = 0 and pool > 0 and (lulcno5 = 3 or lulcno5 = 4 or

lulcno5 = 6)) and (not (rocktype = 2 and lulcno5 = 2)))

and (gradient = 1 or (gradient > 1 and (dsize = 4 or size = 4)))

44) *Fundulus zebrinus* Jordan & Gilbert - plains killifish (Figure 62)

The plains killifish was found in only one segment which is Waller Creek in Austin urban area in 1975.

Habitat:

- Inhabits shallow (rarely deeper than 15 cm) sandy bottomed runs, pools, and backwaters of headwaters, creeks and small to medium rivers;
- Tolerates extremely alkaline and saline streams, and often found where few other fishes can survive;
- Buries headfirst in sand and orients itself with only mouth and eyes are visible. This habit may protect the fish from intense sunlight or may help avoid predators, detect potential prey, or stream desiccation;
- Spawns in summer in small pools over sand and gravel bottom;
- Omnivorous, with insects and other aquatic invertebrates making up bulk of diet.

Prediction SQL script:

(gradient = 1 or (gradient=2 and pool>0)) and (lulc_code<4 or lulc_code=7)

Poeciliidae - livebearers

45) *Gambusia affinis* (Baird & Girard) - western mosquitofish (Figure 63)

The western mosquitofish had a wide distribution in the study area. It was collected in 33 segments of all sizes

Habitat:

- Like shallow, marginal areas (backwater, oxbow) where the water is warm, sluggish and there is considerable aquatic vegetation or other cover;
- Base- or low-gradient waters such as ponds, small pools, ditches draw; less common in moderate gradient streams;
- Clear water;
- In TX varous species of mosquitofish common in many locations and occur throughout the state;
- Fertilization is internal; livebearers; feeds on zooplankton, small insects and detritus.

Prediction SQL script:

(gradient = 1 or gradient > 1 and (valw_3c > 1 or lake = 1 or pool > 0 or mouth = 1 or floodp_cd = 1) and (not (lulcno5 = 1 or lulcno5 = 7)))
and (not (rocktype = 2 and lulcno5 = 2))

46) *Gambusia geiseri* Hubbs & Hubbs - largespring gambusia (Figure 19)

The largespring gambusia is an endemic species of Texas, but not native to the study area. The introduction to Waller Creek failed (Edwards 1975). No other records were found. This species needs constant temperature in the springs. No prediction was made.

47) *Poecilia latipinna* (Lesueur) - sailfin molly (Figure 64)

The sailfin molly was found in 7 segments in the lower part of the drainage. It was collected in large numgers at productive stations (Tilton 1961).

Habitat:

- Occurs in ponds, lakes, sloughs, and quiet, often vegetated, backwaters and pools of streams and also in coastal waters;
- A wide variety of habitats, including springs, lakes and ponds, rivers and streams, drainage ditches, and salt marshes;
- Abundant in tidal ditches and brackish canals;
- Negligible current of bank areas and pools was the preferred habitat;
- Feeds mainly on algae, vascular plants, organic detritus, and mosquito larvae.

Prediction SQL script:

(pool > 0 or lake =1) and (not lulcno5 =3) and(not lulcno5 = 7)

48) *Poecilia reticulata* Peters - guppy (Figure 19)

The guppy was introduced to Waller Creek and disappeared latter in November, 1975 (Edwards 1975).

Biology:

- Locally established in warmwater sites, temperature 68-86 °F (or even higher up to 90°F);

- An ideal temperature for adult guppies is 72 to 76 °F. Fry are often raised in warmer water for the first 2 or 3 months (78 - 80 °F). Requires fairly warm temperatures (23-24 °C) and quiet vegetated water for survival; Barton Spring: water temperature 19.6-21.9 °C;
- Although introduced widely in Texas, the only established population is one found in the San Antonio River near Brackenridge Park;
- No established population in the study area.

No prediction was made.

Moronidae - temperate basses

49) *Morone chrysops* (Rafinesque) - white bass (Figure 65)

The white bass was taken from 16 segments, most of which are the main river and its direct tributaries.

Habitat:

- Deeper pools of moderate-sized to large rivers and open water of lakes and reservoirs.
- In both current and backwater in clear water over a firm sand or rock bottom;
- Intolerant of continuous, high turbidity;
- Stocking in large reservoirs;
- Migrate upstream to spawn;
- After release, eggs sink to the bottom and become attached to rocks;
- Feed: fry on small invertebrates; adults on fish (gizzard and threadfin shad are preferred food items) crutaceans and emerging insects.

Prediction SQL script:

(size > 2 or lake = 1) and (not (lulc_code = 1 or lulc_code = 7))
and (not (lulcno5 = 2 and rocktype = 2))

50) *Morone saxatilis* (Walbaum) - striped bass (Figure 19)

An introduced recreation species, the striped bass were collected in the reservoirs including 7 segments starting from 1985.

Biology:

- Anadromous, inhabits coastal waters and are commonly found in bays but may travel 100 miles inland to spawn;
- Some populations are landlocked . landlocked populations can complete their entire life cycle in freshwater. These have ascended tributaries of the lakes or reservoirs where they and future running water is necessary to keep eggs in motion until hatching;
- 50 miles or more of stream is required for successful hatches;
- Although not native to Texas, the species has been stocked in a number of reservoirs; Because stream flow is required for a successful hatch, most reservoir populations are not self-sustaining and must be maintained through stocking. One notable exception is Lake Texoma along the Red River in northeastern Texas;
- Hybrid striped bass (striped bass crossbred with white bass) are stocked in many areas because of quick growth and good survival characteristics;
- In the study area, Lake Travis and Town Lake have striped basses stocked, and Lake Austin has hybrid striped basses stocked.

No prediction was made.

Centrarchidae - sunfishes

51) Chaenobryttus gulosus (*Lepomis gulosus*) (Cuvier) - warmouth (Figure 66)

Starting from 1947, the warmouth were collected from 39 segments. Thirty-seven of these segments were the main river or its direct tributaries.

Habitat:

- Primarily a lowland species; weedy ditches having little noticeable current, and in swamps, sloughs, natural lakes and borrow pits;

- Elsewhere: oxbow lakes and other overflow waters along the flood plains of streams. exhibits a definite affinity for clear water and thick growths of submergent vegetation.upland areas: in sluggish streams and quiet pools over mud and does well in impoundments;
- Tolerate moderate levels of turbidity and acidic conditions;
- Low gradient.

Prediction SQL script:

((lowland = 1 and (gradient = 1 or (gradient > 1 and (valw_3c > 1 or lake = 1 or mouth = 1 or backwater > 0 or pool > 0)))) or (lowland = 0 and (lake = 1 or (gradient = 1 and (pool > 0 or backwater > 0 or mouth = 1 or floodp_cd = 1 or valw_3c > 2))))) and (not (rocktype = 2 and lulc_code = 2))

52) *Lepomis auritus* (Linnaeus) - redbreast sunfish (Figure 67)

The redbreast sunfish was taken from 58 segments, representing a wide distribution in the drainage

Habitat:

- Rocky and sandy pools or backwaters of creeks and small to medium rivers of low or moderate gradient; rocky and vegetated lake margins with bottoms of sand and mud; also occurs in ponds and reservoirs.
- Mainly a stream-adapted species in its native range, but it has become established in some lakes and ponds; prefer flowing water and are often associated with logs or stumps;
- Elevations of up to 1000 meters; pH variation from 4.8 to 8.4; salinities up to 8%
- Usually clear but occasionlly turbid;
- Often seen in the same habitat as smallmouth bass and rock bass;
- Avoids swamps; based on its distribution; intolerant of the highly acidic waters
- Probably native only as far west as Choctawhatchee drainage, western FL; introduced to southeastern TX.

Prediction SQL script:

((size>2 and (valw_3c>1 or backwater> 0 or lake=1)) or (size<=2 and (lake=1 or pool>0) and gradient<3)) and (not (rocktype=2 and lulc_code=2))

53) *Lepomis cyanellus* Rafinesque - green sunfish (Figure 68)

The green sunfish was collected from 45 segments in a wide range of the drainage starting from 1930.

Habitat:

- Highly adaptable species; found in almost every type of aquatic habitat;
- Tolerate extremes of turbidity, DO, temp, and flow; pioneering speces;
- Most abundant in small creeks and ponds that will not support most other sunfishes;
- In the fluctuating environment of small Prairie streams. by late summer & fall these small streams often consist of series of isolated, stagnant pools, in this habitat green sunfish are often abundant;
- Intermitten streams: that have warm, turbid, muddy bottomed pools containing beds of aquatic plants and populations of other introduced fishes, sole fish, especially polluted by human activity;
- Lake & reservoirs: only abundant in shallow, weedy areas that exclude larger or less tolerant species;
- Rivers: found in riprap and old car bodies;
- Found throughout Texas.

Prediction SQL scripts:

((flow=2 and (pool>0 or gravelpits>0 or mouth=1)) or

((size>2 or (size<=2 and flow=1))) and (gradient<3 or (gradient=3 and valw_3c>1 or backwater>0 or pool>0 or mouth=1)))

54) *Lepomis humilis* (Girard) - orangespotted sunfish (Figure 69)

The orangespotted sunfish has limited occurrence and was found only in 3 segments The reason for its limited population is probably that it has a generally more western range (Tilton 1961).

Habitat:

- Quiet pools of creeks and small to large rivers;
- Tolerant of siltation and continuous high turbidity;
- Commonly found in streams with low or intermittent flow, but occurs less frequently in extreme headwater situations than does the green sunfish;
- Low-gradient streams;avoids streams with high gradient, clear or cool water, and continuous strong flow.

Prediction SQL script:

(gradient = 1 or (gradient > 1 and pool > 0)) and (lulcno5 < 3 or lulcno5 = 7)

55) *Lepomis macrochirus* Rafinesque - bluegill (Figure 70)

Collected from 72 segments, the bluegill was found to have the most even distribution in the drainage. It was also the most abundant sunfish in the lower Colorado River basin and was collected from a greater variety of habitats than any member of the family (Tilton 1961).

Habitat:

- Survive and reproduce under many environmental conditions;
- Do best in warm, shallow lakes, reservoirs, ponds, streams, and sloughs at low elevation broad temperature: 2-5C, 40-41C; optimal 27-32C; greatest abundant along the flood plains of major rivers and nearby streams; intolerant of continuous high turbidity and siltation; survive in low DO;
- Often associate with rooted aquatic plants and with bottoms of silt, sand, or gravel. associate with ponds, lakes, sloughs; thrives best in warm, clear waters where aquatic plants or other cover is presnet;
- Persist through periods of high winter and spring flows by moving into temporary

backwaters or areas of flooded vegetation: any place where this refuge from high current velocities;

- Associate with largemouth bass.

Prediction:

(gradient=1 or (gradient>1 and (pool>0 or backwater> 0 or lake=1 or valw_3c>1 or mouth=1))) and (not (rocktype=2 and lulc_code=2)) and sewage=0 and ((not (lulc_code=1 or lulc_code=7)) or ((lulc_code=1 or lulc_code=7) and (dsize>2)))

56) *Lepomis marginatus* (Holbrook) - dollar sunfish (Figure 71)

Only one occurrence of the dollar sunfish in Onion Creek near Austin was reported in 1971, and probably this is the most western record.

Habitat:

- Lowland;
- Swamp, small sluggish creeks and bayous;
- Relatively unmodified, clear & moderate to heavy aquatic vegetation, mud and detritus bottoms.

Prediction SQL script:

lowland=1 and ((size =4 or floodp_cd =1) or (size < 4 and ((gradient = 3 and (sdiscr_11c >=2 or pool > 0)) or (gradient = 2 and pool > 0) or gradient = 1))) and sewage = 0 and lulcno5 > 1 and (not (lulcno5 =2 and rocktype = 2))

Note: The predicted segments do not cover Segment 873. The species occurred in this segment because of land use/land cover: about 50% is barren, 30% is agriculture and shale and 20% forest.

57) *Lepomis megalotis* (Rafinesque) - longear sunfish (Figure 72)

The longear sunfish had a wide distribution and was collected from 50 segments.

Habitat:

- Clear, permanent-flowing streams having sandy or rocky bottoms;
- Associate with aquatic vegetation, but not an essential requirement;
- Occurs in streams of all sizes but is more abundant in creeks than in large rivers; abundance along the shoreline of most large reservoirs (but typically inhabits small streams and upland parts of rivers, generally absent from downstream lowland sections);
- Avoids strong currents by inhabiting sluggish pools, inlets and waters off the main stream channel of low-gradient;
- Found throughout Texas, except for the headwaters of the Canadian and Brazos rivers;
- Nests scooped out of gravel bars;
- Food: insects and small fish.

Prediction SQL script:

(flow=1 or (flow=2 and (pool>0 or mouth=1 or gravelpits>0 or floodp_cd=1))) and ((not (rocktype=2 and lulc_code=2))) and (gradient<3 or (gradient=3 and pool>0 or floodp_cd=1)) and ((not (lulc_code=1 or lulc_code=7)) or ((lulc_code=1 or lulc_code=7) and (lake=1 or pool>0 or mouth=1)))

58) *Lepomis microlophus* (Günther) - redear sunfish (Figure 73)

Among the 38 segments where the redear sunfish, 33 were in the main river or its direct tributaries. Tilton (1961) found that this species was found in the largest numbers in deep eddies off the swift main channel ofthe upper river. This is in the list of stocking species of the TPWD.

Habitat:
- Inhabits ponds, swamps, lakes; and vegetated pools, usually with mud or sand;
- Small to medium rivers;
- Also occurs in warm, clear and quiet waters rich in vegetation and snags;
- Found near the bottom in warm water with little current and abundant aquatic vegetation; more tolerant of silt than most other sunfishes;

- Its preference for the upper Colorado River is more pronounced than other common sunfish.abundant in the tailrace water of Tom Miller Dam and the river within the city limits of Austin. below this point, a rapid drop in total numbers was noted found in the largest numbers in deep eddies off the swift main channel of the upper river;
- Spawn in warm months in deeper water than most other sunfish, congregating in spawning beds ; nests are saucer-shaped depressions in gravel or silt;
- Food: snails, also insect larvae and cladocerans; seldom feeds at surface;
- Widely stocked in reservoirs and ponds Through Texas.

Prediction SQL script:

((lulcno5 = 4 or lulcno5_2 = 4) or ((not (lulcno5 = 4 or lulcno5_2 = 4)) and (lake = 1 or (pool >0 and flow = 1) or mouth = 1 or backwater > 0))) and (gradient = 1 or (gradient > 1 and (valw_3c > 1 or lake = 1 or (pool > 0 and flow = 1) or mouth = 1 or backwater > 0 or spring > 0 or belowdam = 1)))

59) *Lepomis punctatus* (Valenciennes) - spotted sunfish (Figure 74)

Collections from 29 segments yielded this species. Twenty-seven of these segments are the main river or its direct tributaries.

Habitat:

- Creeks and small to medium rivers, and swamps;
- Inhabits heavily vegetated ponds, lakes, pools occurs over mud or sand;
- Common in quiet or moderately flowing waters with heavy vegetation or other cover;
- Lowland: more sluggish ditches where submerged aquatic plants are present; plateau: occurs in quiet pools near boulders and submerged logs, and in clear, heavily vegetated backwaters of the major streams that enter the lowlands.

Prediction SQL script:

(lowland = 1 or (lowland = 0 and dsize = 4 and (not lulc_code = 7))) and (gradient = 1 or (gradient > 1 and (lake = 1 or pool > 0 or mouth = 1 or backwater > 0 or valw_3c > 1))) and ((not lulc_code = 1) and (not (rocktype = 2 and lulcno5 = 2)) or floodp_cd = 1)

60) *Micropterus dolomieu* Lacepede - smallmouth bass (Figure 75)

In Texas smallmouth bass have been stocked in numerous areas, particularly streams of the Edwards Plateau (Chilton 1997). It was collected from 14 segments 13 of which are in the reservoirs or its direct tributaries. There were no records of this species before 1988.

Habitat:

- Inhabits large (>100 acres, > 30 feet deep) shallow rocky areas of lakes, clear and gravel-bottom runs and flowing pools of rivers, cool flowing streams and reservoirs fed by such streams; and gravel substrate; Intolerant of high turbidity and siltation;
- Occurs only in streams that maintain flow except during the most severe droughts;
- In the upper Mississippi River it is restricted to the rocky shoals below navigation dams where stream-like conditions still prevail; the damming of optimal bass streams drastically reduced the suitable habitat for this species;
- The ecological replacement for the spotted bass and the largemouth bass in the clear, cool, permanent-flowing streams;
- Spawn in the spring water temperature approach 60 °F; nests located near shore in lakes, or downstream from boulders in streams;
- Food: young - plankton and immature aquatic insects
  adults - crayfish, fishes, and aquatic and terrestrial insects;
- Hybridize easily with Guadalupe bass.

Prediction SQL script:

(flow = 1 or (flow = 2 and dsize = 4)) and ((not lulc_code = 1 or lulc_code = 7) or ((lulc_code = 1 or lulc_code = 7) and dsize = 4)) and (not (lulcno5 = 2 and rocktype = 2))

61) *Micropterus punctulatus* (Rafinesque) - spotted bass (Figure 76)

The spotted bass was taken from 9 segments in or close to the main river.

Habitat:

- Inhabits clear, gravelly flowing pools and runs of creeks and small to medium rivers; also occupies impoundments; in large reservoirs, generally found at depths greater than those occupied by other black basses;
- Inhabits permanent-flowing waters that are warmer and slightly more turbid than those where the smallmouth bass occurs;
- In the main channels of large rivers within its area of occurrence the spotted bass occurs almost to the exclusion of other black basses;
- Largely replaced by the smallmouth bass in cool, spring-fed streams, and by the largemouth bass in standing waters;
- Rock or gravel are usually chosen as suitable spawning areas at water temperatures of 57-74 °F, nest depths vary widely;
- In Texas spotted bass are native to portions of east texas from the Guadalupe River to the Red River, exclusive of the Edwards Plateau region.

Prediction SQL script:

flow =1 and (spring = 0 or (BelowDam = 0 or (BelowDam = 1 and (AbvDamMans = 1 or AbvDamTomM = 1 or AbvDamLong = 1)))) and lulc_code > 1 and (not (lulc_code = 2 and rocktype = 2))

62) *Micropterus salmoides* (Lacèpéde) - largemouth bass (Figure 77)

Taken from 68 segments, the largemouth bass has the second most even distribution. This species is probably more wide ranging in its habitat selection than the other basses (Tilton 1961). It is in the list of stocking species of TPWD.

Habitat:

- Characteristic of natural lowland lakes, man-made impoundments of all sizes, the permanent pools of small streams with low or intermittent flow, and the quiet backwaters of large rivers; more characteristic of standing than of flowing waters;
- Prefer quiet, warm, shallow (<6m) waters of moderate clarity and beds of aquatic plants

are the usual habitat; survives quite well in a variety of environments; intolerant of excessive turbidity and siltation;

- Largely replaced by one of the other basses in streams with continuous strong flow;
- Spawning in the spring; water temperature 60 °F; nest in quiet, vegetated water, but will use any substrate besides soft mud, including submerged logs, nests are usually built in 2-8 feet of water;
- Feed on other fish and large invertebates such as crayfish, fry on zooplankton and insect larvae.

Prediction SQL script:

((flow=1 and (gradient=1 or (gradient>1 and (pool>0 or backwater> 0 or lake=1 or valw_3c>1)))) or (flow=2 and (pool>0 or lake=1 or dsize=3 or dsize=4)))
and (not (rocktype=2 and lulcno5=2)) and sewage=0 and
((not (lulc_code=1 or lulc_code=7)) or ((lulc_code=1 or lulc_code=7) and (dsize>2)))

63) *Micropterus treculii* (Vaillant & Bocourt) - Guadalupe bass (Figure 78)

The Guadalupe bass was collected from 46 segments. Tilton (1961) note that it was dominant over the limited numbers of Micropterus punctulatus may be correlated with the filtering action of the dams and the necessary clear water in the upper river segment, and that it has dissimilar habitat requirements iwth a resulting lack of competition for survival.

Habitat:

- Found only in Texas; endemic to the northern and eastern Edwards Plateau including headwaters of the San Antonio River, the Guadalupe River above Gonzales, the Colorado River north of Austin, and portions of the Brazos River drainage. Relatively small populations can also be found outside of the Edwards Plateau, primarily in the lower Colorado River;
- Propensity for gravel riffles, runs and fast-flowing pools; abundant in downstream sections of small streams, where it inhabits shallow, swift waters;
- Absence from extreme headwaters;

- Moderately tolerant of high turbidity and variable temperatures;
- Build gravel nests for spawning, preferabley in shallow water;
- Food: piscivory, fry - invertebrates;
- Hybridization with stocked smallmouth bass has become a serious problem. The TPWD has suspended stocking smallmouths in areas where Guadalupes may be affected.

Prediction SQL script:

(flow=1 or (flow=2 and dsize=4 and (lake=1 or mouth=1 or floodp_cd=1))) and ((gradient>1) or (gradient=1 and (lowland=0 or (lowland=1 and (size>2 or pool>0 or sdiscr_11c=3 or sdiscr_11c=6 or sdiscr_11c=8)))))

64) *Pomoxis annularis* Rafinesque - white crappie (Figure 79)

The white crappie was collected from 13 segments of the main river or close tributaries .

Habitat:

- Often found in turbid water, but avoids excessively turbid streams and those kept continuously cool by spring flow;
- Standing timber;
- Live primarily in rivers and reservoirs; prefers quiet waters;
- In Texas white crappie are native to the eastern 2/3 of the state, now found statewide except for the upper portions of the Rio Grande and Pecos drainages.

Prediction SQL script:

spring = 0 and ((not lulc_code = 7) or (lulc_code = 7 and lake = 1)) and (not (lulc_code = 2 and rocktype = 2)) and (size >=3 or (size < 3 and dsize = 4))

65) *Pomoxis nigromaculatus* (Lesueur) - black crappie (Figure 80)

The black crappie was collected from only 2 segments in Lake Travis during 1988-1992.

Habitat:

- Quiet warm waters, avoids streams that are excessively turbid and those kept continuously cool by spring flow, absence of noticeable current;

- Clear water, abundant cover in the form of submerged timber or aquatic vegetation.

Prediction SQL script:

spring =0 and (gradient =1 and (pool > 0 or lake = 1 or
gravelpits > 0 or valw_3c > 1)) and sewage = 0 and
not (rocktype =2 and lulcno5 = 2) and
not(lulcno5 = 1 and lulcno5 = 7)

Percidae - perches & darters

66) *Etheostoma grahami* (Girard) - Rio Grande darter (Figure 81)

Obviously introduced from Rio Grande River, the Rio Grande darter occurred only in Barton Springs in 1993.

Habitat:

- Spring-fed;
- Perennially flowing creek;
- Creeks / small rivers;
- Gravel and rubble.

Prediction SQL script:

flow=1 and spring=1 and not size=4 and (not (lulc_code =2 and rocktype = 2))

67) *Etheostoma chlorosoma* (Hay) - bluntnose darter (Figure 82)

The bluntnose darter was taken from 2 segments in Barton Springs and Town Lake. Hubbs and Hettler (1959) reported it was restricted to a small population in the upper river.

Habitat:

- Muddy pools and backwaters, quiet waters;
- Low-gradient streams.

Prediction SQL script:

(pool > 0 or (size = 4 and valw_3c > 0)) and lulcno5 < 7 and gradient < 3

68) *Etheostoma lepidum* (Baird & Girard) - greenthroat darter (Figure 83)

The greenthroat darter only occurs in Texas and New Mexico. It was collected from 14 segments. And its limited population is an indication of a speceis at the limits of its (eastern) range (Tilton 1961).

Habitat:

- Riffle; prefer spring-fed streams and vegetated riffle;
- Non-turbid, vegetated with substrates from bedrock to silt covered;
- Also found in swift-flowing streams and springs, as well as in gravel-bottomed littoral areas of lentic habitats subject to wave action;
- Known only from the Pecos River system in southeastern New Mexico, and from the Edwards Plateau region in central Texas;
- Eggs are deposited on vegetation or on the undersides of rocks;
- Omnivore-eats plants and animals.

Prediction SQL script:

((size < 3 and pool > 0) or (size >= 3 and valw_3c > 1 and lake = 0)) and
(not (lulc_code = 1 or lulc_code = 7) or
((lulc_code = 1 or lulc_code = 7) and lake = 1)) and
(not (lulcno5 = 2 and rocktype = 2))

69) *Etheostoma spectabile* (Agassiz) - orangethroat darter (Figure 84)

The orangethroat darter was collected from 9 segments. Tilton (1961) noted that it was confined to a short stretch of the Colorado River beginning below Tom Miller Dam and extending only to the eeastern city limits of Austin. From this GAP study, it shows that this species extends to the upper part to the far north in Hamilton Creek and to the east in Onion Creek.

Habitat:

- Northern Texas in the USA; Gulf drainages (Trinity River to San Antonio River) of Texas, mostly on Edwards Plateau;
- Hardwater;
- Gravelly/rocky bottom;
- Sluggish, slow-moderate current riffles/pools having current to prevent the deposition of silt;
- Characteristic of small creeks and spring branches;
- Avoids streams with continuous strong flow where conditions favor E. caeruleum.

Prediction SQL script:

rocktype <3 and (not lulc_code = 1) and (not (lulc_code = 2 and rocktype = 2))
and not (lowland = 1 and size = 4 and floodp_cd = 1) and ((gradient = 1)
or (gradient > 1 and pool > 0))

70) *Percina caprodes* (Rafinesque) - logperch (Figure 85)

The logperch was found in 26 segments, most of which were in the main river. Tilton (1961) reported that it was taken more consistently in the tributaries than in the river.

Habitat:

- A variety of stream types: mountain streams, moderate and large sized rivers of medium to low gradient, oxbow and impoundments; but penetrates into headwater creeks only if they maintain large, permanent pools;
- Avoids streams that are continuously turbid or excessively silty, or that lack well defined gravelly riffles. excessive turbidity and siltation is the main factors excluding this species from lowland;
- Found in the deeper and more sluggish sections of riffles, but also occurs in pools if the bottom is mostly free of silt;
- In reservoirs the logperch occurs along gravelly waveswept shores.

Prediction SQL script:

(size > 2 or (size <= 2 and (pool > 0 or mouth = 1 or lake = 1))) and (not (lulc_code = 1 or lulc_code = 7)) and (not (lulcno5 = 2 and rocktype = 2)) and (gradient = 1 or (gradient > 1 and (valw_3c > 1 or pool > 0 or mouth = 1 or lake = 1)))

71) *Percina carbonaria* (Baird & Girard) - Texas logperch (Figure 86)

The Texas logperch is endemic to Texas, occurring mostly on the Edwards Plateau (Lee 1983). It was found in 3 segments including the Hamilton Creek in the far northern part of the study area, the Barton Springs and its closest segment of the Colorado River.

Habitat:

- Inhabits rocky riffles and runs of small to medium rivers;
- Prefers deep, clean, fast rocky riffles.

Prediction SQL script:

gradient = 1 and size<4 and (not lulcno5 =1 and not lulcno5 = 7) and (not (rocktype = 2 and lulcno5 = 2))

72) *Percina macrolepida* Stevenson - bigscale logperch (Figure 87)

The bigscale logperch was found only in 4 segments and collected before 1969 only. This species occurs only in Texas and surrounding areas.

Habitat:

- Typical habitat: larger streams with strong, non-turbulent flows; also found in impoundments. a wide variety habitats. most common in the slower moving stretches of warm, clear streams or in the shallow waters of lakes;
- Preferred substrate varies from silt to rubble;
- Eggs are laid on aquatic plants. This species occurs in deep rivers, preferably with a strong current and rubble-gravel substrate; however, it is also found in rivers with nearly imperceptible flow and in impoundments;
- In California, most abundant in the muddy bottomed, turbid sloughs of the Delta and

lower Sacramento River. also found in the warm summer pools of the intermittent sections;

- Bottom fish (incapable of sustained swimming); little seasonal migration.

Prediction SQL script:

spring=0 and Not lulc_code=7 and not (lulcno5=2 and rocktype=2)

and (gradient=3 or lake=1)

Note: two segments directly below the Dam of Lake Travis are taken out

73) *Percina sciera* (Swain) - dusky darter (Figure 88)

All of the 10 segments where the dusky darter was collected are in the lower part of the drainage. Tilton (1961) stated that with an exception of occurrence in an intermittent tributary after rains it was found confined to the river channel and absent from the tributaries. The records shows this is not necessary.

Habitat:

- Lowland;
- Clear, intolerant of turbidity, pollution & silt, sand/gravel bottom;
- Low-gradient/strong flow.

Prediction SQL script:

lowland=1 and sewage=0 and (not (lulc_code=1 or lulc_code=7)) and not (lulcno5=2 & rocktype=2) and gradientke=1 and size=3 or size=4

Sciaenidae - drums

74) *Aplodinotus grunniens* Rafinesque - freshwater drum (Figure 89)

The freshwater drum was taken from 30 segments. With the exception of the Hamilton Creek, all others are in the main channel or its direct tributaries. Freshwater Drums prefer large lakes or rivers (Lee et al. 1980). The Hamilton creek must have a large pool because it is usually found in large pools (Pflieger 1992).

Habitat:

- Occurs in bottoms of medium to large rivers and lakes;
- Seems to prefer large, silty lakes and rivers, but occurs in wide variety of habitats;
- Avoids strong current but is tolerant of high turbidity;
- Spawn at water temp of 19-22 °C; eggs float until hatch;
- Feeds on mollusks, benthic crustaceans, and insects;
- Known to produce sound.

Prediction SQL script:

(size = 4 and (valw_3c > 1 or (valw_3c <= 1 and lake = 1))) or (size < 4 and dsize = 4 and lake = 1)

Cichlidae - cichlids

75) *Cichlasoma cyanoguttatum* (Baird and Girard) - Rio Grande cichlid (Figure 90)
Introduced from its native range Rio Grande River, Rio Grande cichlid was found in 31 segments, Thirty-two of which are in the main river or its direct tributaries. Tilton (1961) stated that its distribution may be based on water temperature requirements.

Habitat:

- A number of populations have been established in large springs and rivers of central Texas' Edwards Plateau including the San Marcos, Guadalupe, San Antonio and Colorado rivers;
- Inhabits pools and runs of small to large rivers;
- Prefers warm water and vegetation; Minimum temp tolerances in the Colorado River (5 °C); very sensitive to cold water temp;
- Do well in heated water, and in spring-fed waters with constant favorable temp;
- Sluggish or no current in deep weedy backwaters, over deep silt or mud;
- Prefers the main river as its occurrence in a tributary above the mouth was rare except for seasonal concentrations in the warmer waters of Barton Creek. The distribution of the Rio Grande cichlid may be based on water temperature requirements, and its greater

upriver abundance correlated with the warmer waters of Barton Creek and the tailrace waters of Tom Miller Dam;

- Great abundance in the Colorado River, inhabits Waller Creek in the summer for food and to breed; first seen in May, along shore, very shallow water, sunny locations with a sandy substrate, with mostly overhanging shore vegetation in the vicinity or overhanging brush;
- Spawn in early spring;
- Feeds on worms, crustaceans, insects and plant matter.

Prediction SQL script:

(size >= 3 or (size < 3 and dsize = 4 and (floodp_cd = 1 or lake = 1 or mouth = 1 or spring = 1))) and (gradient = 1 or (gradient > 1 and (lake = 1 or backwater > 0 or mouth = 1 or belowdam = 1))) and (not (rocktype = 2 and lulcno5 = 2))

76) *Oreochromis aureus* (Steindachner, 1864) - Blue Tilapia (Figure 91)

An introduced species, the blue tilapia was recorded in 2 segments of Lake Travisbetween 1988 and 1992.

Habitat:

- Most common in warmwater reservoirs and has been reported or is established in more than 30 Texas counties;
- It is established in the Rio Grande, San Antonio, and Guadalupe drainages, and in parts of the Colorado River drainage;
- The low lethal temperature differs from different literatures: 6.2 °C, 9-11 °C, 8 °C.

Prediction SQL script:

Lake=1

Note: The water temperature in Lake Marble Falls near Max Starcke Dam ranges from 7.9-31.66 °C. This lake was predicted not to have the blue Tilapia occurrence. Other lakes have appropriate temperatures for this species.

Mugilidae - mullets

77) *Mugil cephalus* Linnaeus - striped mullet (Figure 92)

The striped mullet is a migratory species from marine. Its collection were from only 4 segments of the main channel and only from 1952 to 1960. It was apparently affected by the Tom Miller Dam

Habitat:

- Coastal species that often enters estuaries and rivers; Usually in schools over sand or mud bottom and dense vegetation;
- Often ascending coastal rivers for considerable distances, stopping at Fall Line;
- Taken from all habitats in the river and its tributaries; prefer open water of estuarine and freshwater environments;
- Reproduction takes place in the sea;
- Feed on zooplankton, benthic organisms and detritus. Adult fish tend to feed mainly on algae while inhabiting fresh waters.

Prediction SQL script:

size >= 3 and abvLonghornDam = 0

78) *Mugil curema* Valenciennes - white mullet (Figure 93)

Taken only from one segment, the occurrence of the white mullet is rare. Like Mugil cephalus, it is a migratory species and affected by dams.

Habitat:

- Offshore spawning from spring thru summer, move into ocean waters in fall and winter;
- Opportunistic feeder that ingests quantities of organically rich substrate;
- Few records of this species far inland are available.

Prediction SQL script:

(not(lulcno5 = 2 and rocktype = 2)) and lulcno5 < 7 and sewage = 0

and gravelpits < 3 and (not lulcno5 = 3)

Characidae - Characins

79) *Piaractus brachypomus* (Cuvier) - Pirapitinga (pirapatinga) (Figure 19)

The pirapitinga was taken from only 1 segment in Town Lake. It is native to the upper and middle Amazon River, and the specimen might be the occasional pet release. It cannot breed in the study area.

Habitat:

For the Red Paco to breed their natural Amazonian water conditions must exist:

Temperature 22-26 °C (72-79 °F).

The Colorado River does not have these conditions (7.9 -31 °C) and cannot meet this species' requirement. No prediction was made.

The predictions using logistic regression

The models

The coefficients of logistic regression model are shown in Table 4. The equation for the relationship between Species Occurrence and the predictors was:

logit (Species occurrence) =

$$\frac{1}{1+Exp(-(B0+B1size+B2Sdiscr11+B3Gradient+B4Valw3c+B5Flow+B6Geology+B7Floodplain+B8LULC+B9soilpH))}$$

where B0 denotes the intercept constant for the model;

B1, ..., B9 represent the coefficients for the independent variables;

size, Sdiscr11, ..., soilpH are the independent variables.

Take *Lepomis gulosus* as an example. Variable soilpH caused numerical problems and was removed from the model. Variables Gradient, Valw3c and Geology had the probabilities for removal greater than 0.15 and remained in the model. The equation for Species *Lepomis gulosus* was

logit (Species occurrence) =

$$\frac{1}{1+Exp(-(-8.507+1.279*Size+0.354*Sdiscr11+1.601*Flow+1.827*Floodplain+0.459*LULC))}$$

The table shows that Variable soilpH caused numerical problems for most of species (16/17). Variable Geology plays a role in the prediction only for two species. Variables Size, Sdiscr11 and LULC are important predictors to make prediction for most species.

The prediction maps

The species occurrence predicted using logistic regression with the 95 sampling segments and 9 variables were shown in Figures from 94 to 110. Compared to the prediction maps using habitat affinities, the logistic-regression prediction identified fewer segments for species occurrence but it also did not cover a greater portion of actual-occurred segments. For example, for Species *Lepomis gulosus*, while the habitat-affinity model predicted 193 occurring segments out of 424 and did not include 1 actual occurring segment, the logistic regression model predicted 70 occurring segments and ignored 7 actual occurring segments.

Table 4. Coefficients of the logistic regression model

species	Presence Number	Chance Accuracy	cut-point	Accuracy	B0	Size	Sdiscr11	Gradient	ValW 3C	Flow	Geology	Flood plain	LULC	SoilpH
Lepomis punctatus	28	73	0.3	72.6	-5.371	0.867	0.503	1.066			-1.767		0.348	1.25
Aplodinotus grunniens	29	72	0.5	84.2	-8.477	2.14	0.382		-1.212	num prob *			0.583	num prob
Cichlasoma cyanoguttatum	30	71	0.47	81.1	-5.242	0.97	0.494						0.318	num prob
Menidia beryllina	31	70	0.48	74.7	-4.835	1.712			-1.032			3.107		num prob
Lepomis microlophus	32	69.1	0.46	71.6	-3.518	1.331	0.269		-0.97					
Cyprinus carpio	32	69.1	0.5	83.2	-7.921	2.09	0.33		-1.016			1.921	0.444	num prob
Gambusia affinis	33	68.3	0.3	68.4	6.470	1.313			0.969	-1.947	-1.066	-2.646		
Lepomis gulosus	35	66.8	0.52	74.7	-8.507	1.279	0.354			1.601		1.827	0.459	num prob
Ictalurus punctatus	38	65	0.41	72.6	-1.889	1.079	0.409	-0.921						num prob
Lepomis cyanellus	42	63.3	0.45	69.5	-0.477	0.324	0.316	-0.704				-2.928	0.601	
Dorosoma cepedianum	43	63.1	0.55	80	-6.953	1.583	1.001						0.418	
Micropterus treculi	43	63	0.5	72.6	-2.946	0.527	0.497	-0.575					0.513	
Cyprinella venusta	44	62.8	0.5	68.4	1.949			-0.519		-0.89				
Lepomis megalotis	48	62.5	0.59	65.3	2.038		0.331			-1.654		-1.647		
Lepomis auritus	55	64	0.61	74.7	-2.648								0.773	
Micropterus salmoides	63	69	0.71	71.6	-0.297	0.734	0.891			-1.064				
Lepomis macrochirus	67	73	0.63	75.8	-2.682	0.586	0.722					num prob	0.445	

*num prob: numerical problem

Conservation

Figures 111 through 117 show the layers (variables) used to generate the conservation priority map. The nonpoint source pollution model for water quality (Figure 111) shows that urban areas usually cause lowest water quality, and agriculture is ranked next. Balcones Canyonlands, Barton Creek and the upper parts of Onion Creek have good water quality. The segments in the eastern portion of the study area, corresponding to the Texas Blackland Prairie, are affected by the human activities and thus more anthropogenic (Figure 112). More natural segments are west to this area, such as Barton Creek, the upper Onion Creek and the segments in the Balcones Canyonlands. Road densities are low for most segments except those near the city of Austin (Figure 113). Four dams are located on the Colorado River with the largest, the Mansfield Dam, creating Lake Travis (Figure 114). Others are small. With the above four layers combined, the map of the environmental quality of the valley segments (Figure 115) shows that best quality segments were the ones of Barton Creek, the upper reaches of Onion Creek and those in and near the Balcones Canyonlands.

The highest number of species (50, more than 2/3 of the total number of species collected in the study area) occurred in the segments of the lowest Barton Creek, the mid to lowest Onion Creek, and several segments of the lower portion of the Colorado River (Figure 116). The mid-lower portion of Barton Creek, the channel and its direct tributary segments of Lake Travis and above, ranked the next highest. For the number of species of special concern (endemic, threatened and lower state ranks), the lowest segments of Barton Creek and Onion Creek, and the three segments of the lower Colorado River in the study area ranked highest (Figure 117). The second higest appeared to be the segments adjacent to the ones ranked highest.

The results of overlaying the environmental quality and the biological index demonstrates the segments having potential conservation importance (Figure 118). Three groups of segments stand out: 1) Four segments of Barton Creek starting from the confluence of the Colorado River upstream; 2) The segments right upstream of and west to the City of Austin, including three segments of the Colorado River, Panther Hollow Creek, Coldwater Creek, and adjacent segments; and 3) Two segments of the lower

Onion Creek and two segments of the lowest Colorado River right downstream of the City of Austin.

Currently, the Barton Creek has been in the conservation plan (The Nature Conservancy 2003). The segments in the other two groups are the candidate sites for protecting the fish community in the Hydrologic Unit 12090205. The two segments of Onion Creek are located either in agricultural areas and the two segments of the lower Colorado River right downstream of the metropolitan Austin area. It is not feasible to develop a conservation plan to restrict the human activities in these areas. These segments are also separate far from each other. Therefore, the third group of segments, which are upstream and west to the City of Austin, is the only ones prioritized for conservation. The third group is thus the GAP in the study area.

CHAPTER IV
DISCUSSION

The goal of this study is twofold. First, it applies the GAP analysis approach to predict biodiversity and it utilizes said approach to identify conservation sites on a watershed scale in Texas. As such, this study demonstrates the feasibility of the GAP approach for the study of riverine ecosystems in Texas. In order to identify the three groups of valley segments potentially suitable for conservation; we classified the riverine ecosystem, mapped the known distributions, predicted the biodiversity content, modeled the environmental quality and graphed the ichthyofaunal indexes. The three groups are listed as follows: 1) the lower Barton Creek, 2) the group of valley segments including three segments of the Colorado River and adjacent streams upstream of and west to the City of Austin, and 3) two segments of the Onion Creek and two segments of the Colorado River right downstream of the City Austin. The second group containing the lower Barton Creek, is in accordance with the current conservation plan for the geographic area (The Nature Conservancy 2003). This indicates that the GAP analysis methodology is appropriate for the study of the aquatic ecosystem in Central Texas.

Among the three groups of valley segments that show a high priority for aquatic conservation, the third group (Figure 118) is composed of two segments found in the Onion Creek stream and two found in the Colorado River. The former is located in an agricultural area and latter is downstream of and adjacent to the Austin urban area. As a result of these factors, it might be difficult to develop a conservation plan to restrict human activities such as growing crops, using pesticides, manufacturing goods, or using detergent. The distance between these segments may also prevent them from creating a good conservation site, and if only one is selected that would result in an area that is geographically insignificant and biologically not as diverse. It would be challenging to include all the segments in a conservation network because of their distance from each other. As a result, the third ecosystem unit was removed from the proposed conservation site leaving only the first and second units as described above. Additionally, because the first unit is currently a preserve stream, the second unit was designated as a conservation priority site in an effort to fill the GAP.

Fish sampling data provided the basic information for the GAP analysis and therefore data collection is an important step. Unfortunately, the number of sampling segments was only 23.5% of the total. Some 12-digit HUs do not have any sampling data. This situation often occurred in the areas far from the roads or urban areas. Some species have only one or two collections or were collected from only one or two segments. These data provide less information for predicting species occurrence on a local scale. As could be seen from this paper, the limited data made both models of the habitat affinity and the logistic regression less accurate. Sampling efforts should be included in future studies, particularly on the segments and in the HUs never sampled. Building a data center for fish or other aquatic species in a local or regional scale is worth considering. It could facilitate researchers, both saving time and providing complete sampling information.

The variables used to classify the riverine ecosystem into valley segment types were basically adopted from MoRAP (Annis et al. 2002). The MoRAP model uses temperature on a state-wide scale. They classified the aquatic ecosystem into the natural types, and thus predicted the species occurrence under the assumption that aquatic species will occur in suitable natural environments. However, in reality, fish samples were taken on a site under the influence of land use/land cover. In the logistic regression model, the land use/land cover was not removed from the model and was a predictor of the occurrence of most species. Patterns of species richness and changes in species occurrence are related to land use and land cover (Rivard et al. 2000). It has been a major parameter in the land GAP (Thompson et al. 1996; Cassidy et al. 1997). It affects water quality (Saunders et al. 1996; Adamus and Bergman 1995; Lindsey et al. 1998). It also has an effect on riparian cover. It is an appropriate and necessary variable in the riverine ecosystems. On the other hand, the land use and land cover have been changing over time. What the land use and land cover was when the fish were taken might be different than that when we mapped and predicted species occurrence. In this study, the assumption was made for mapping and predicting that the land use and land cover changes little during the period from collecting samples to mapping ecosystems. In future studies, the change of land use and land cover should be considered.

More variables need to be developed in the classification of the streams. The eight basic variables correspond to fish macrohabitat on a stream segment scale. Variables on a finer scale of microhabitat are necessary for predicting the species occurrence, especially when using habitat-affinity model. Some species, e.g., *Notropis amabilis* and *Campostoma anomalum*, prefer riffle conditions. Though riffles are the most common of turbulent fast water in low gradient alluvial channels and are found in plane-bed, pool-riffle, regime, and braided reaches (Hauer and Lamberti 1996, Allen 1995, Hawkins et al. 1993), no information is available for the relationship between riffles and upland channels and it is hard to correlate the riffles to any one of the eight variables. This caused problems in making predictions. This study found the information on the pool from the USGS 7.5' DRG and combined the pool and the gradient to make inference for the riffle/pool. The pools marked on the DRG may be different than the pools in the riffle/pool. The stream substrate is another example. It could be related to some extent to the rocktype (geology), but most of the time the fish is selective about the size of the bed materials. For example, one fish species prefers sand and another species is choosy about boulder. Again, people relate the substrate to gradient (Meixler 1999). However, high-gradient stream segments may have some portion where gradient is low and pools exist. Sand, silt and mud could accumulate here. Obviously, aquatic vegetation is an important variable of fish habitat. It should be included in future studies. Riparian vegetation may also be a candidate variable for fish habitat because riparian cover may affect soil erosion, sediments, sunlight, temperature and organic matter. Meixler (1999) took riparian vegetation cover as a variable when classifying streams for macroinvertebrate. Edwards (1976) noted some fish species prefer swimming around the water with vegetation overhanging.

The precision of georeferencing varied. Some records had GPS coordinates and could be georeferenced precisely. Some collections' records on localities were rough. For example, a collection from TNHC recorded the sampling locality as "narrows above Spicewood". This is probably the reason of the difference of the predicted and actual distribution maps of *Notropis shumardi*. Since narrow is hard to identify from the DRG, this information could be read in at least two ways, upstream above Soccord or back to the road from which the collector entered the stream bed. Either way would locate the sampling site on the segment of headwater. However, the habitat affinities of this species are "closely confined to large rivers" This kind of record, therefore, caused a precision problem.

Some of the assumptions used in the predictions of habitat-affinity models were based on the previous studies or reports. For example, the first assumption about riparian and aquatic vegetation was based on the studies of Klein (1979) and reports of U.S. Environmental Protection Agency (2002) and University of Michigan (2004). Klein pointed out that bank alterations during sewerline installations, channel realignment projects and other construction activities resulted in reductions in the amount of shading afforded urban streams. The two-to-four widening of the channel due to increased runoff and enlargement not only reduces the amount of the stream shaded, but also results in shallower water depths. U.S. Environmental Protection Agency and University of Michigan stated that urbanization has had significant impacts on the stream quality including increased frequency of flooding and peak flow volumes, increased sediment loadings, loss of aquatic/riparian habitat, changes in stream physical characteristics (channel width and depth), decreased base flow, and increased stream temperature, loss of fish populations, and soil erosion, and delivery of pollutants to rivers, streams, lakes and ocean. The second assumption was based on the findings of Crawford and Lenat (1989). After examined chemical and physical characteristics and the biota of streams in different land-use areas, they concluded that the stream draining the forested watershed have the best water quality, that the stream draining the agricultural watershed had intermediate water quality, and that the stream draining the urban watershed exhibited the most impaired water quality. An assumption instead of a finding was used because streams in other land-use areas were not examined.

Correction could be made while working on the prediction of species distribution by checking all the available literature and data. Regarding the temperature tolerance of Species *Cichlasoma cyanoguttatu*, Hubbs (in Lee et al., 1980) reported a lower temperature tolerance of 14 °C for fish in the Colorado River in Austin, Texas, whereas Shafland and Pestrak (1982) reported a lower lethal temperature of 5 °C for this species under experimental conditions. This species occurred in 30 segments in the study area. The temperature records showed that the low water temperature ranged from 7 to 10 °C (LCRA 2000). This verified that the low temperature defined by Shafland and Pestrak was probably correct.

Both of the two prediction models, the habitat-affinity model and the logistic regression model, have advantages and disadvantages. The former tends to be more subjective, but the model could be refined to make almost all of the species sampled as predicted and could take advantage of the existing previous general records from localities other than the study area and make full use of limited records. While the latter usually are more objective, but some certain number of segments where the fish samples were actually collected were not predicted as occurrence. The logistic regression model cannot use the limited records. Many other models for predicting species occurrence were developed (Scott et al. 2002). The statistical and mathematic models usually require a minimum number of the cases. Obviously this requirement could not always be met. This problem also exists in some software programs. The GARP (Payne and Stockwell 1994), for example, requires 20 sample points. When this happens, the habitat-affinity modeling has to be employed though it is more subjective. The combination use of the two should complete the prediction work fairly well.

The minimum number of cases per independent variable is suggested to be 10 (Schwab 2002). However, research is needed to determine if 10 is too stringent a requirement (Hosmer and Lemeshow 2000). In this study, the logistic regression was used to make prediction of species occurrence as a reference and comparison purpose. The cases to variables ratios were 3-6:1.

The sampling methods varied for each collection effort. For example, the TPWD usually use boat electrofishing, roving creel, seine and trawl (Magnelia et al. 2002). The anglers used rod and reel. Not all species occurring in the streams could be collected. For example, Megnolia et al. (2002) reported that freshwater drum were not caught in abundance electrofishing, yet they appeared to be an important sport fish species for Colorado River bank anglers. Electrofishing may have underestimated their abundance. Species absence probably was due to the sampling methods. It is possible the species is present, but it was not detected during the survey. The ability to detect a species is a function of the number of vulnerable individuals and the ability to capture the species (Bayley and Peterson 2001). Peterson et al. (2003) used species capture-recapture theory (Williams et al. 2002) and the program CAPTURE (Rexstad and Burnham 1991) to calculate the species detection probability which was used as weight during model fitting and for estimating probabilities of species presences. This method may be a good way to model the species distribution and make prediction of species occurrence. However, that requires a relative complete history of capture using the same capture method. This approach is not feasible in this study because of the large variation of the sampling methods and long sampling periods.

There may be several reasons for the differences (gaps) between the predicted occurrence and the actual distribution. Some species are migratory and were caught before the dams were built. Also, as mentioned above, the land use/land cover has been changing over time. The conditions when the species were caught no longer exist. The prediction model could not reflect the change and, therefore, was limited in predicting this species. Lastly, the georeferencing precision as described above may cause the gaps.

The nonpoint pollution water quality model (Adamus and Bergman 1995; Sanders et al. 1996) was used as a factor of the environmental quality. This model estimates the input of the pollutants based on the land use and land cover. On the other hand, a certain portion of the segments in the study area has water quality stations set up. The measured concentrations of pollutants apparently are more accurate. Research is needed to determine how the actual pollutant data could be integrated into prediction models.

More explorations are needed to integrate the influence of dams into the models. Dams brought about significant impacts in upstream and downstream environments (Graf 1985). The volume above the dam is much greater than a regular stream and the volume below the dam much smaller. The water quality model used did reflect this change. Research is also needed to create a model which could reflect the hydrologic alteration generated by dam.

A separate score for land use/land cover was generated to evaluate the extent of human alteration and thus the environmental quality of segments. This variable has been used to create the water quality model, but the land use/land cover may have affects on the fish habitat other than the output of pollutants. For instance, while streams in the forest area may have logs, falling leaves on the substrates, clearer and less sunlight penetrated, streams in the urban area tend to have cemented banks, more turbid and more exposed to sunlight. And these factors may have effects on fish distribution.

The Texas conservation data center did not list *Percina carbonaria* as endemic (TxCDC 2003). The literature (Lee et al. 1983; Froese and Pauly 2004) showed that *Percina carbonaria* is endemic to Edwards Plateau and occurs only in Texas. It was taken into account for the species of special concern.

Predicted fish diversity is expected to be highest in midsize streams. All segments with the number of species greater than 50 are either of the lower portion of the principle tributaries (i.e., Barton Creek and Onion Creek) or of Colorado River. This finding is in accordance with that of Mexiler and Mark (1999). However, not all these segments have good water quality (Figure 111, 115). This may be due to the dams prevent the fish from entering the segments with good water quality or caused by not enough information was input into the model.

Some data sources were unavailable and might prevent production of more accurate results. Spawning sites are crucial for a population to sustain in aquatic ecosystems. They should be a factor when developing conservation priorities. Water pH, as noted by Groves et al. (2002), is a variable for fish macrohabitat. Because of the data availability and the relative small homogeneous study area, water pH was not mapped as layer. The soil pH was used instead.

The scale used in this study to develop the conservation priorities is macrohabitat - valley segment. FitzHugh (2003) described predicting biodiversity on Aquatic Ecological Systems (AES). Missouri Resource Assessment Partnership (MoRAP, Sowa 1998) used both AES and valley segment for developing conservation priorities. As AES is a broader scale, it may probably be more appropriate when working on a broader regional or statewide scale. Also, it was found that almost all segments with high conservation priorities congregate together into groups (Figure 118). This phenomenon could also be found in the conservation maps developed by MoRAP (2002).

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APPENDIX A

FIELD DEFINITIONS OF FISH DATABASE

SamplePntID

Data Type: Number: Integer

Definition: The unique identification number of a sampling point

SampleID

Data Type: Integer

Definition: The unique value assigned to a community sample of species.

Stream

Data Type: Text

Definition: The name of the stream where a sample was collected.

Locality

Data Type: Text

Definition: The place where the sample was taken

Month

Data Type: Integer

Definition: The month the sample was collected.

Day

Data Type: Integer

Definition: The day the sample was collected.

Year

Data Type: Integer

Definition: The year the sample was collected.

Collectors

Data Type: Text

Definition: The collectors of the sample

Sources

Data Type: Text

Definition: Miscellaneous information about the sample or source.

SpeciesID

Data Type: Long Integer

Definition: The unique code used to identify a species. This is usually the

Taxonomic Serial Number used by the Integrated Taxonomic Information System (ITIS), a taxonomic database administered by the U.S. Department of Agriculture and developed in partnership with several federal agencies.

Scientific

Data Type: Text

Definition: The scientific name of the species.

Common

Data Type: Text

Definition: The common name of the species.

Introduced

Data Type: Integer

Definition: 1 – exotic (not native to the US)

2 – native to the US but transplanted outside their native range

21 – failed

22 – collected

23 – established

Endemism

Data Type: Text

Definition: Endemic to Texas

Srank

Data Type: Text

Definition: The State Rank of the Species.

Grank

Data Type: Text

Definition: The Global Rank of the Species.

FedStatus

Data Type: Text

Definition: The federal classification of the species.

StCode

Data Type: Text

Definition: The state classification of the species.

Phylum

Data Type: Text

Definition: The Family to which a species belongs.

Class

Data Type: Text

Definition: The Class to which a species belongs.

Order

Data Type: Text

Definition: The Order to which a species belongs.

Family

Data Type: Text

Definition: The Family to which a species belongs.

Genus

Data Type: Text

Definition: The Genus to which a species belongs.

ReachID

Data Type: Text

Definition: The 14-digit National Hydrography Dataset (NHD), code identifying a stream reach or series of reaches.

SegID

Data Type: Text

Definition: The code that uniquely identifies a specific arc (stream reach) in an NHD stream file.

HU12

Data Type: Long Integer

Definition: The code that identifies the 12-digit hydrologic unit (catalog unit) in which a stream reach resides.

UTMX

Data Type: Double

Definition: The horizontal coordinate or UTM projection Zone 14

UTMY

Data Type: Double

Definition: The longitudinal coordinate or UTM projection Zone 14

Latitude

Data Type: Degree Minute Second

Definition: Latitude coordinate

Longitude

Data Type: Degree Minute Second

Definition: Longitude coordinate

CategoryID

Data Type: long integer

Definition: Each category corresponds to a collection record, usually one or more fish of a species in one sampling effort

Quantity

Data Type: Text

Definition: The number of fish for that category

APPENDIX B

SPECIES OF SPECIAL CONCERN

Species	Endemic	State Code	State Rank
Micropterus treculi	Y		S3
Percina carbonaria	Y		S4
Notropis buccula	Y		S2
Notropis oxyrhynchus	Y		S3
Erimyzon sucetta			S3
Etheostoma lepidum			S3
Etheostoma grahami		T	S2
Lythrurus fumeus			S3
Lythrurus umbratilis			S2
Notropis stramineus			S3
Scartomyzon congestus			S3

Endemic: Endemic to Texas

S2: Imperiled in state, vary rare, vulnerable to extirpation, 6 to 20 occurrences.

S3: Rare of uncommon in state, 21 to 100 occurrences.

S4: Apparently secure in state.

Data from Texas Conservation Data Center.

APPENDIX C

MAPS: STUDY AREA, VALLEY SEGMENT TYPES,

SAMPLING POINTS, AND ACTUAL AND

PREDICTED DISTRIBUTION OF FISH

USING HABITAT-AFFINITY MODEL

IN THE HYDROLOGIC UNIT

12090205 OF CENTRAL

TEXAS

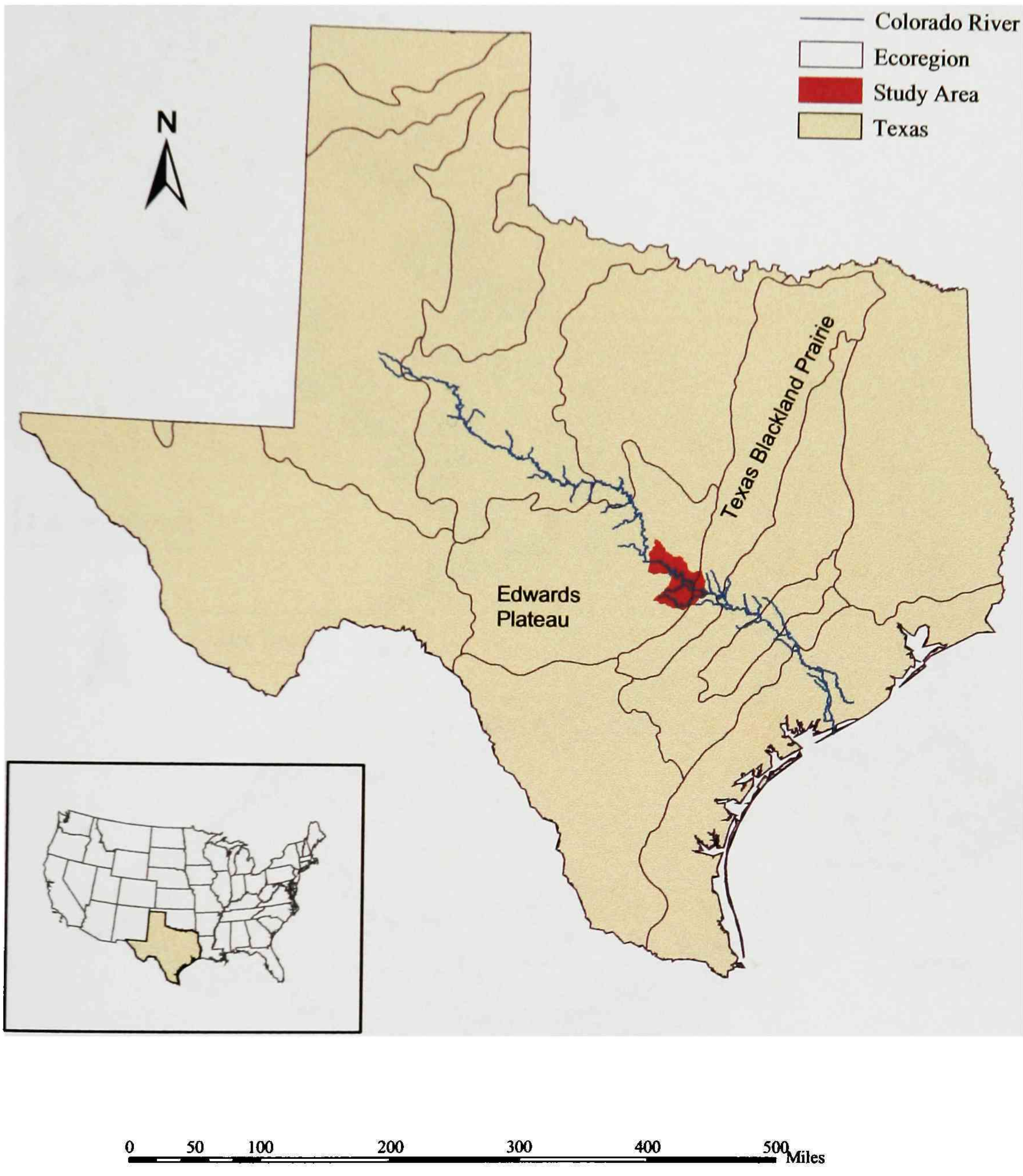

Figure 3. Location of the Hydrologic Unit 12090205

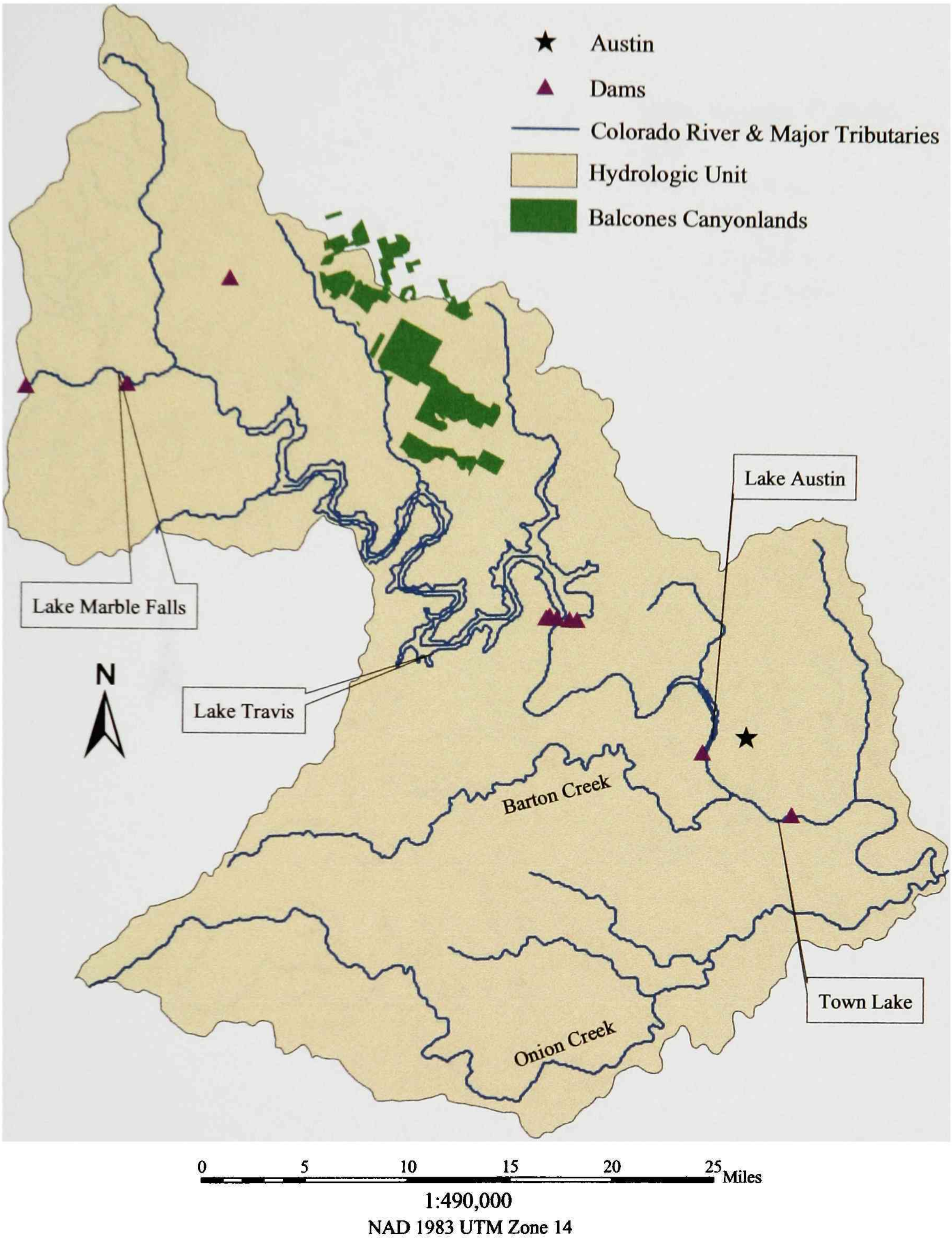

Figure 4. Colorado River and major tributaries (Reach Files 1 from EPA), dams and the Balcones Canyonlands Preserve in the Hydrologic Unit of Central Texas

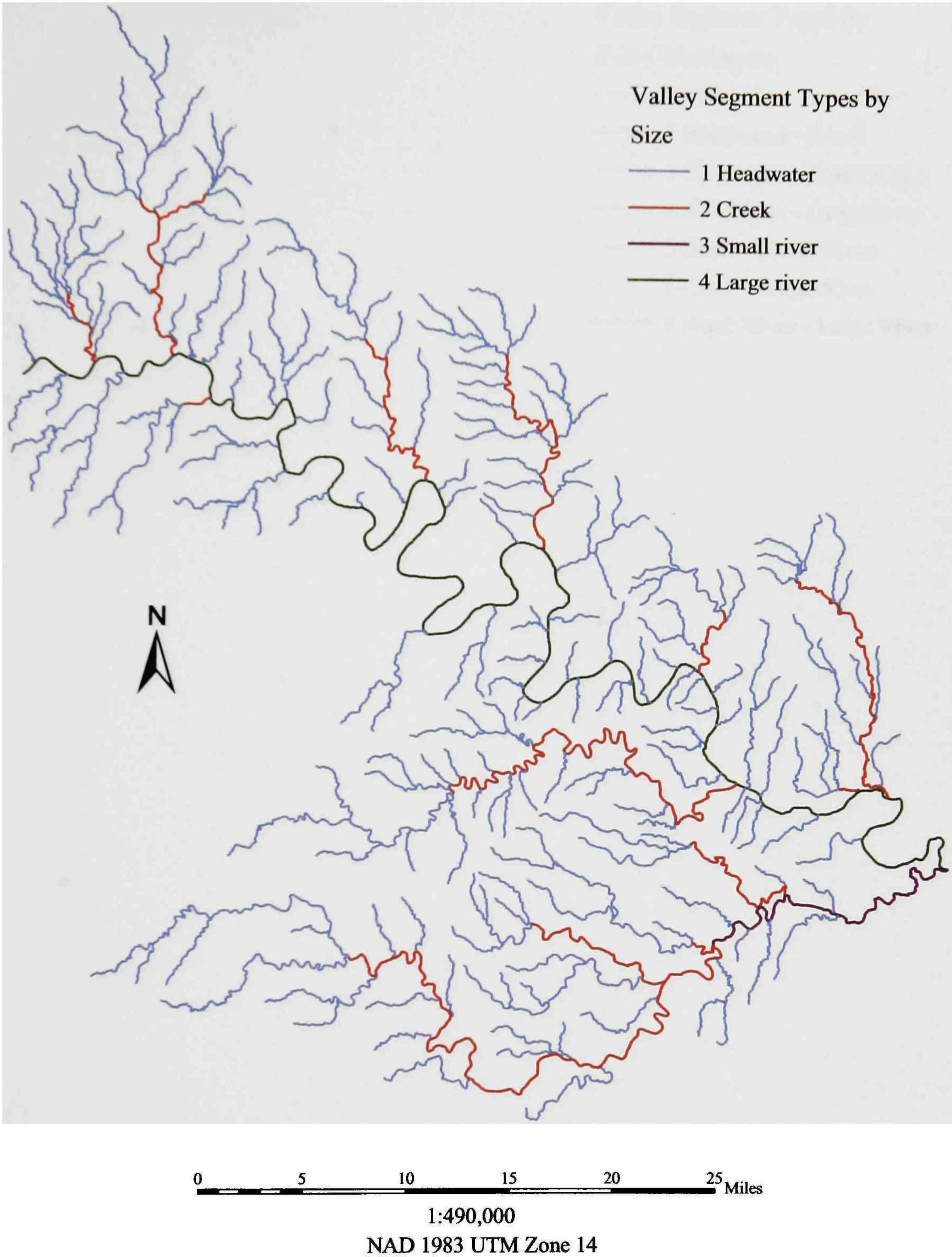

Figure 5. Valley segment types by Size in the Hydrologic Unit 12090205 of Central Texas

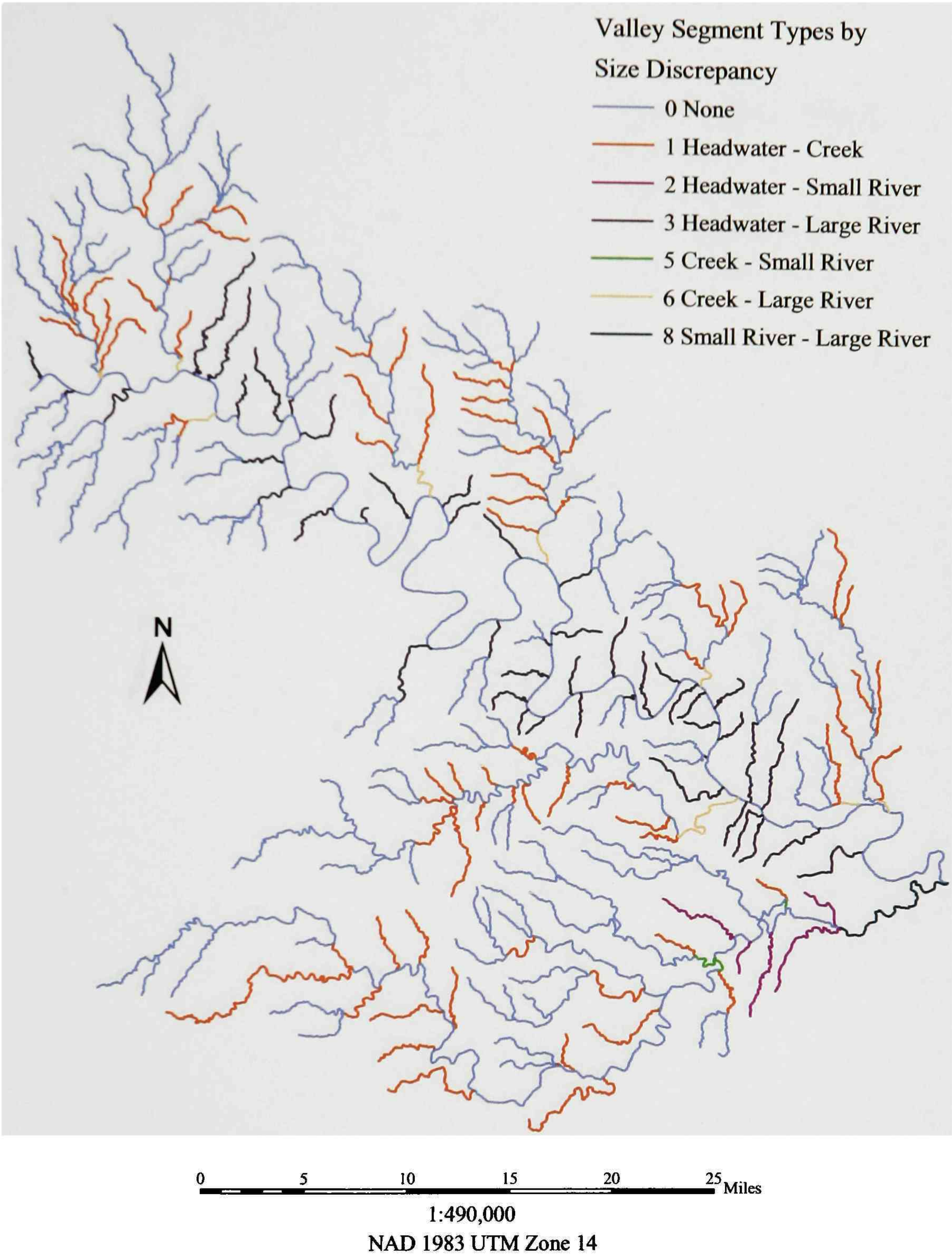

Figure 6. Valley segment types by Size Discrepancy in the Hydrologic Unit 12090205 of Central Texas

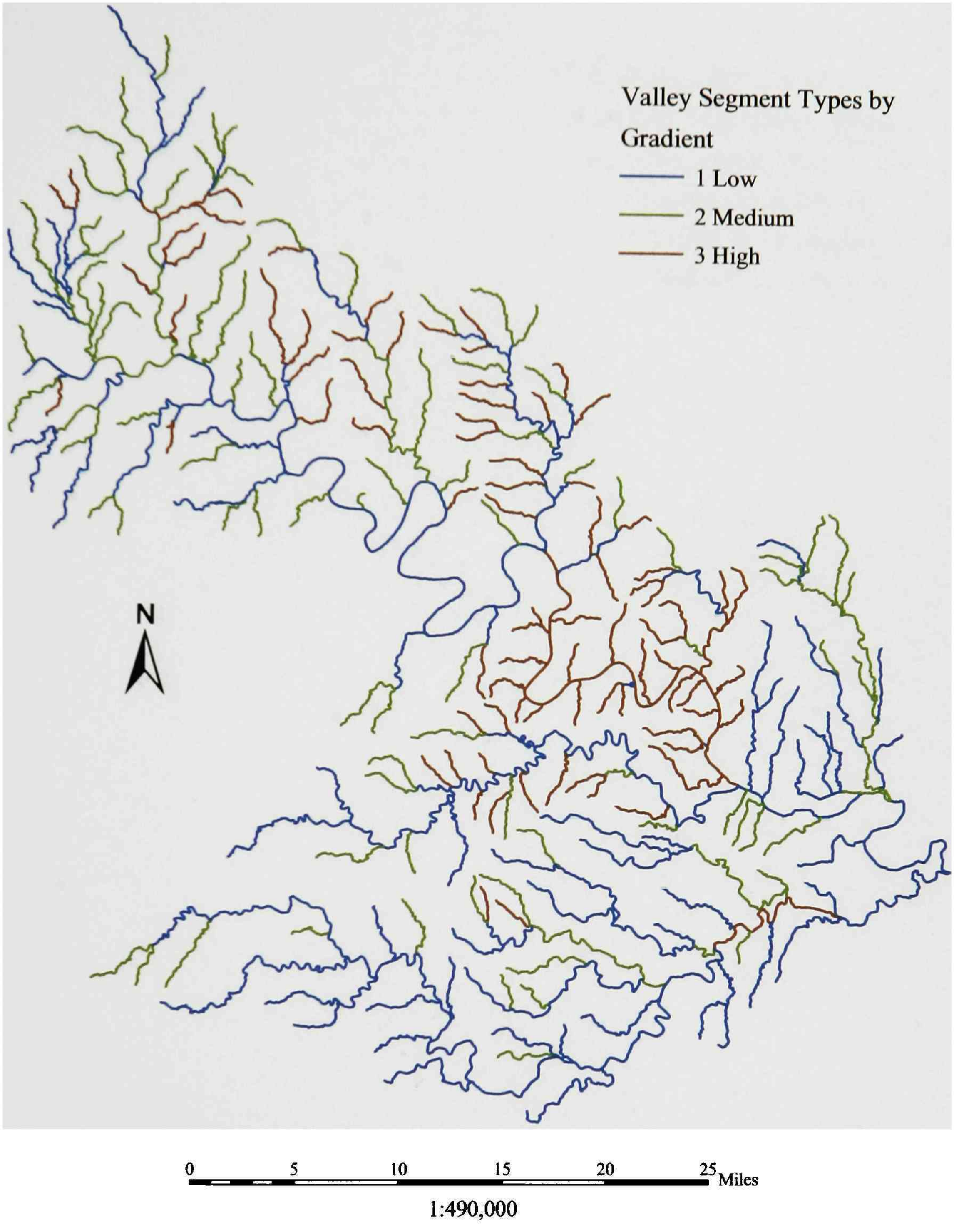

Figure 7. Valley segment types by Gradient in the Hydrologic Unit 12090205 of Central Texas

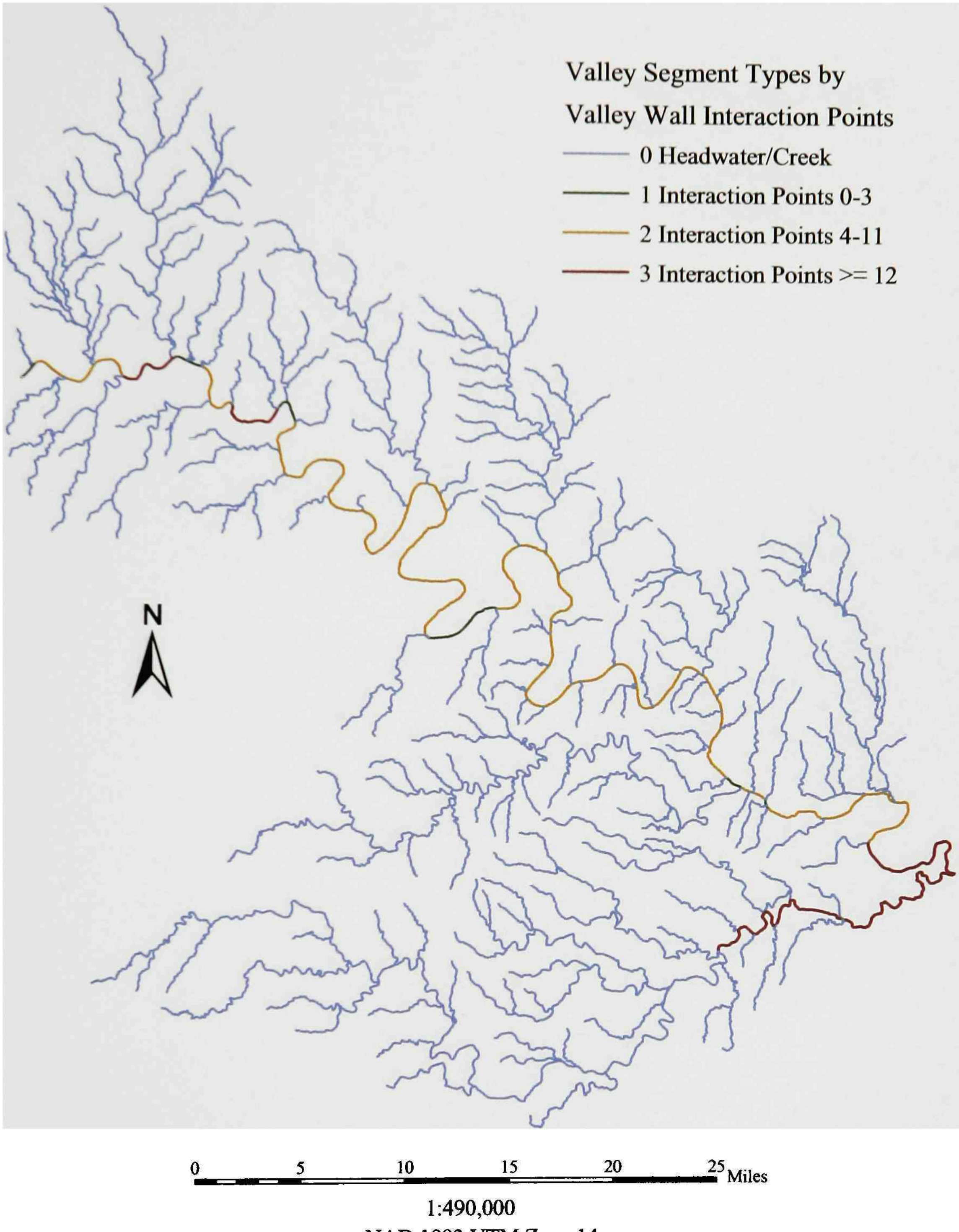

Figure 8. Valley segment types by Valley Wall Interaction Points in the Hydrologic Unit 12090205 of Central Texas

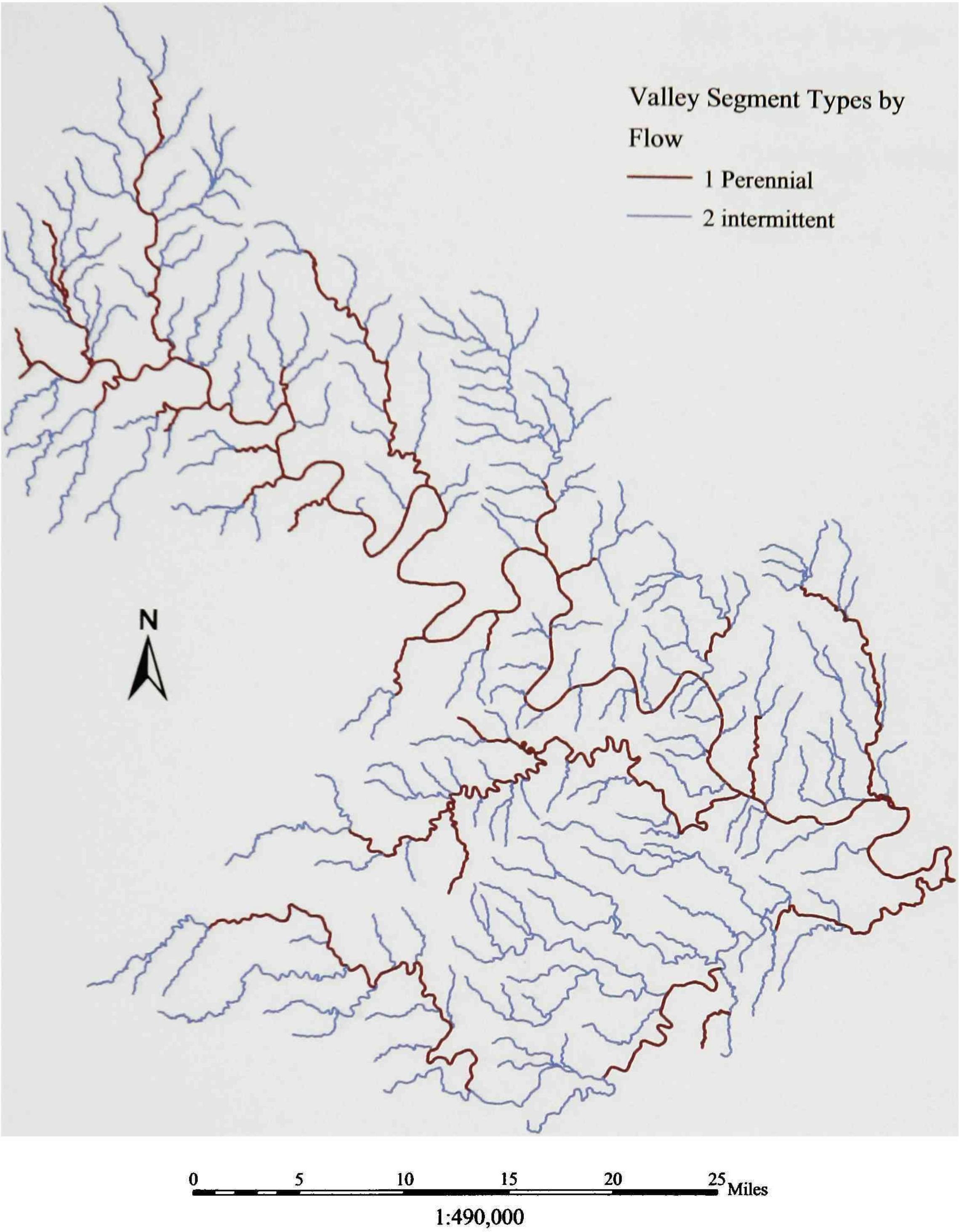

Figure 9. Valley segment types by Flow in the Hydrologic Unit 12090205 of Central Texas

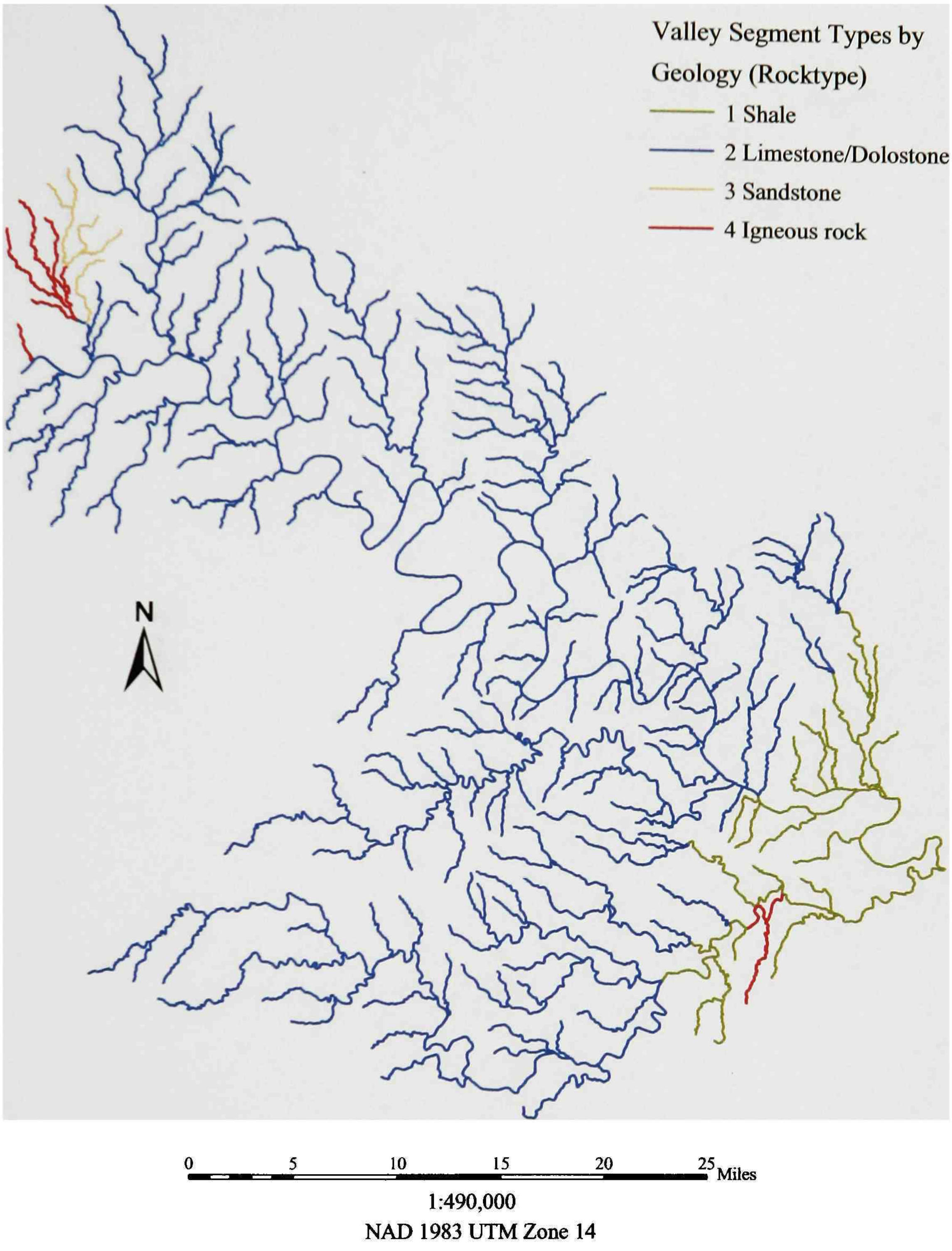

Figure 10. Valley segment types by Geology (Rocktype) in the Hydrologic Unit 12090205 of Central Texas

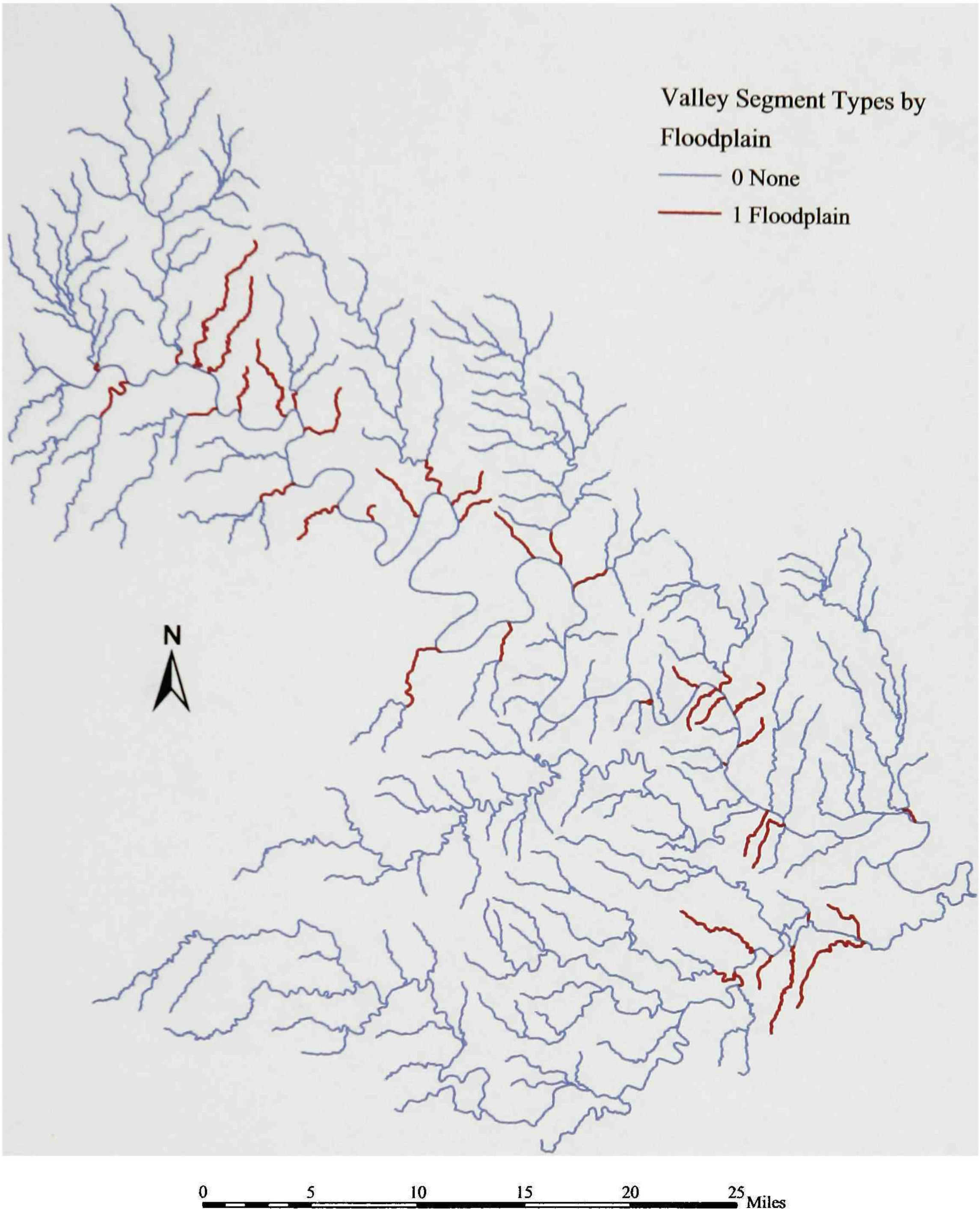

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Figure 11. Valley segment types by Floodplain in the Hydrologic Unit 12090205 of Central Texas

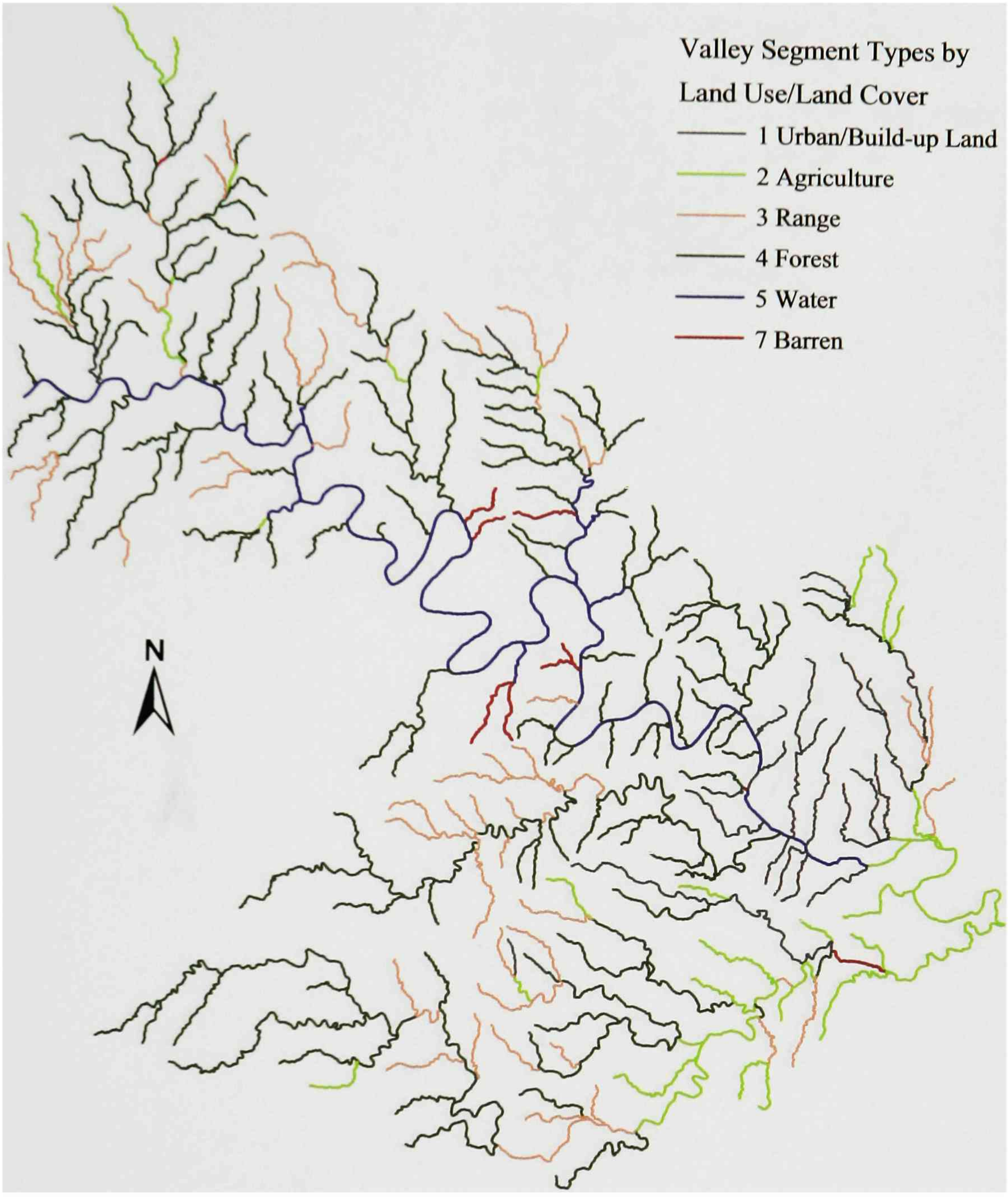

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Figure 12. Valley segment types by Land Use/Land Cover in the Hydrologic Unit 12090205 of Central Texas

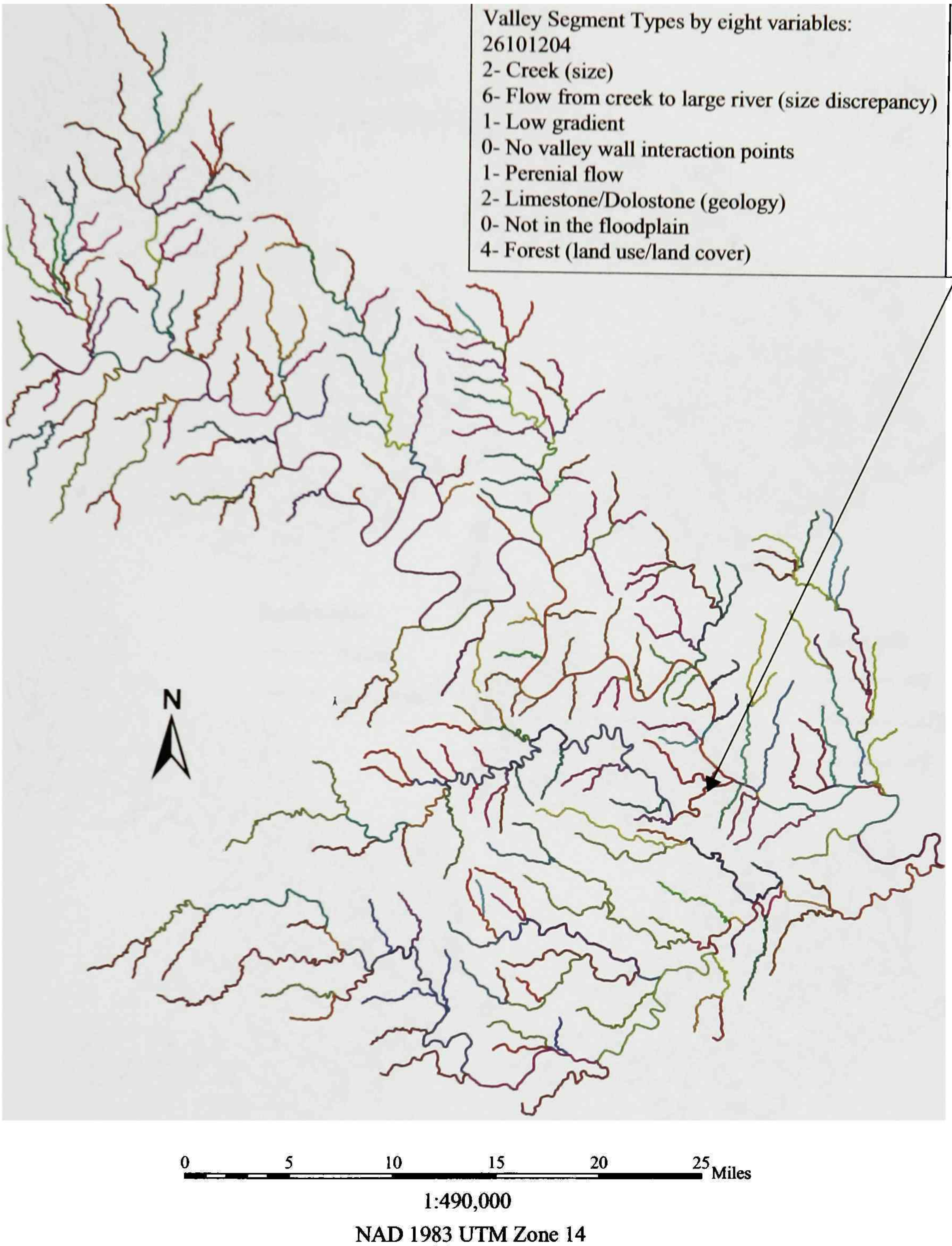

Figure 13. Valley segment types by eight variables in the Hydrologic Unit 12090205 of Central Texas

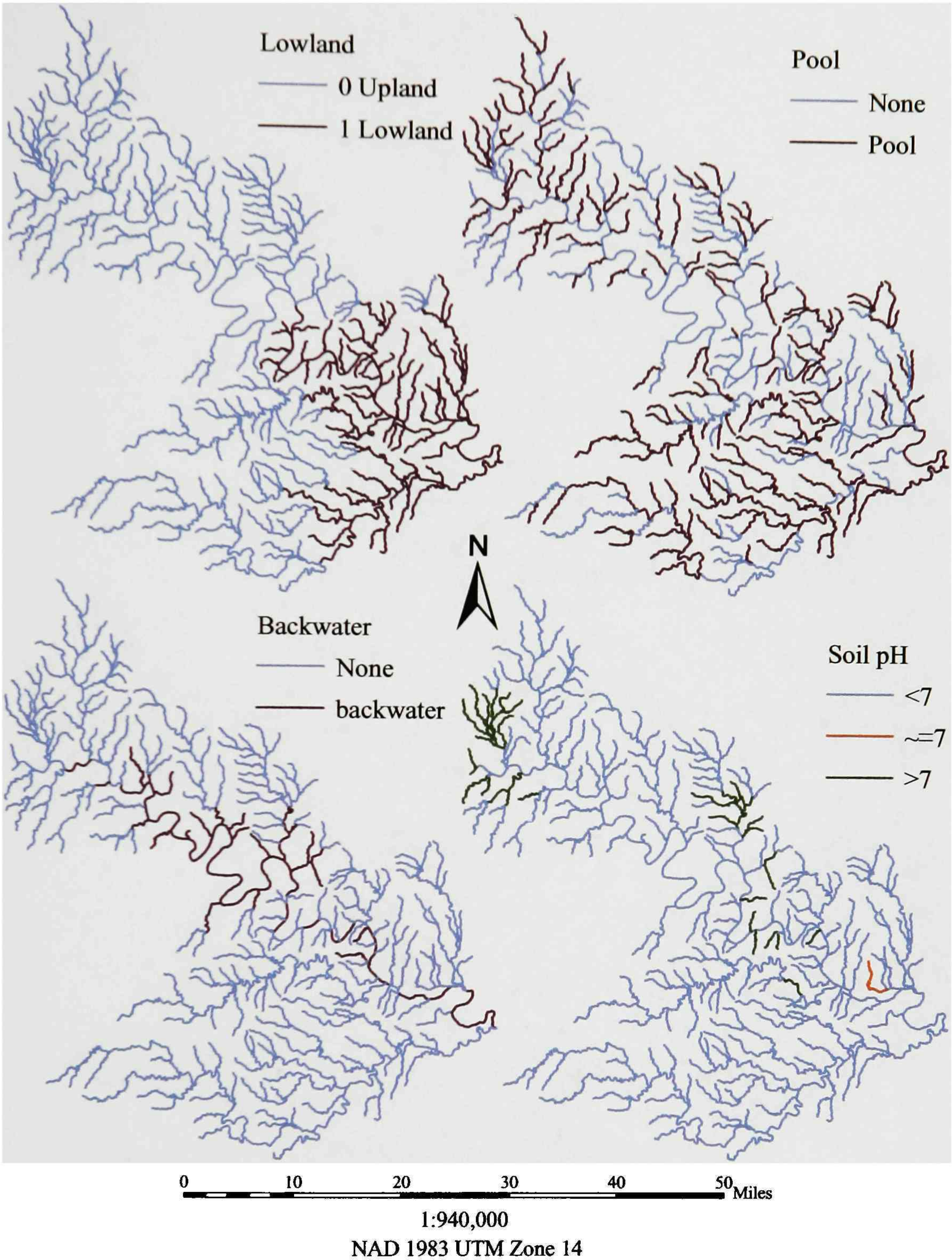

Figure 14. Valley segment types by SoilpH, Backwater, Pool and Lowland in the Hydroloic Unit 12090205 of Central Texas

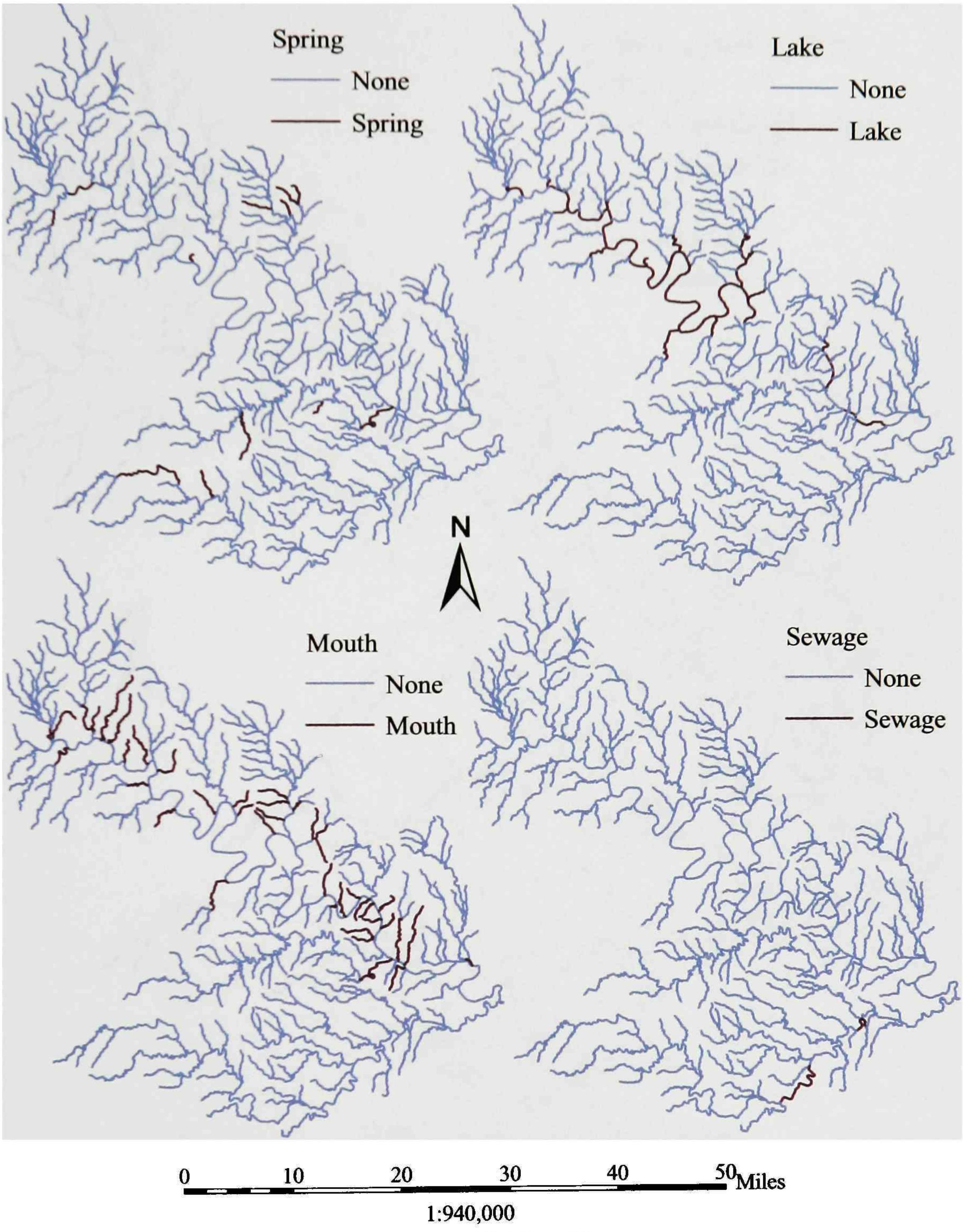

Figure 15. Valley segment types by Spring, Lake, Mouth and Sewage in the Hydroloic Unit 12090205 of Central Texas

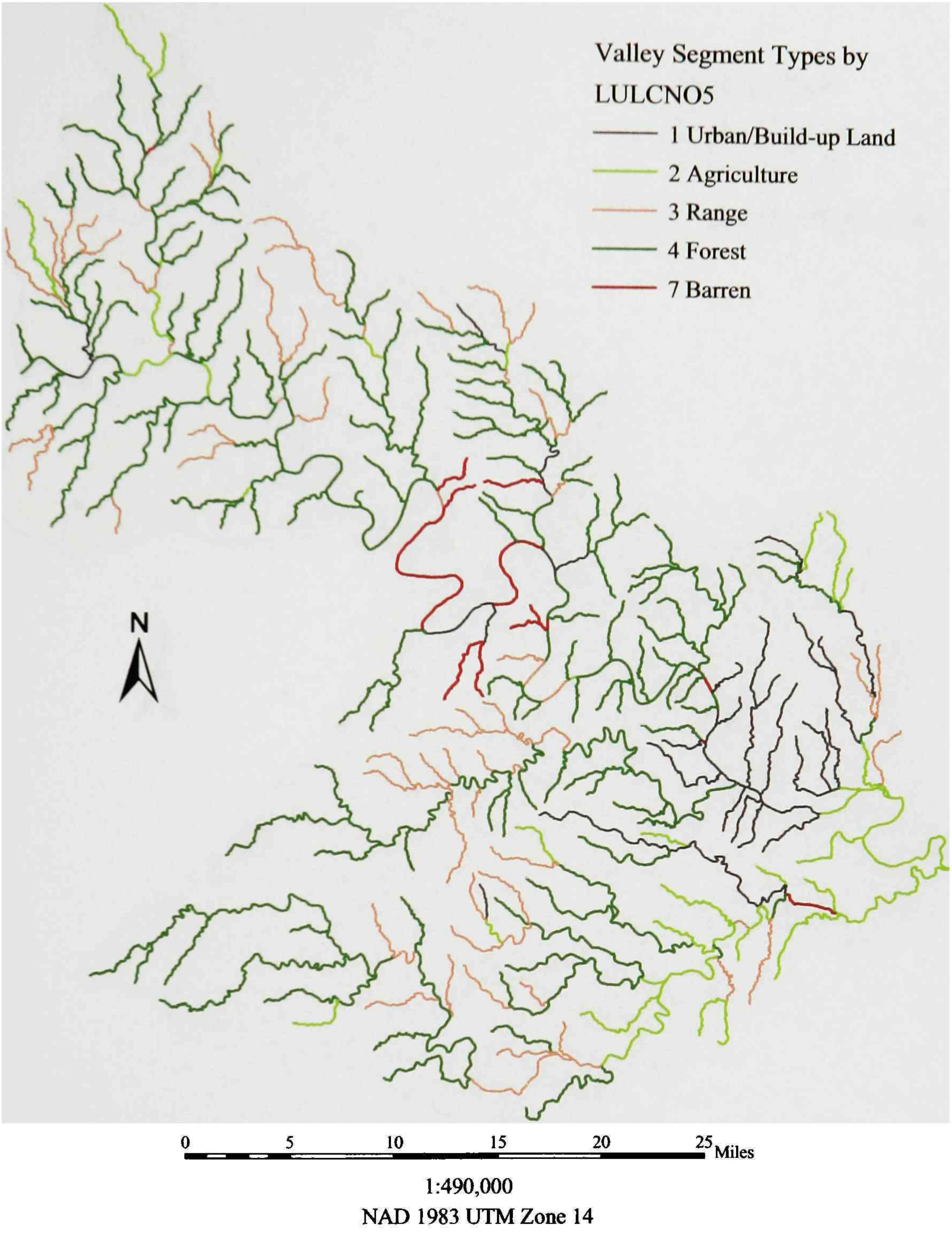

Figure 16. Valley segment types by Land Use/Land Cover (LULC) with Water (LULC code 5) replaced by the Land Use/Land Cover of the segment's bank in the Hydrologic Unit 12090205 of Central Texas

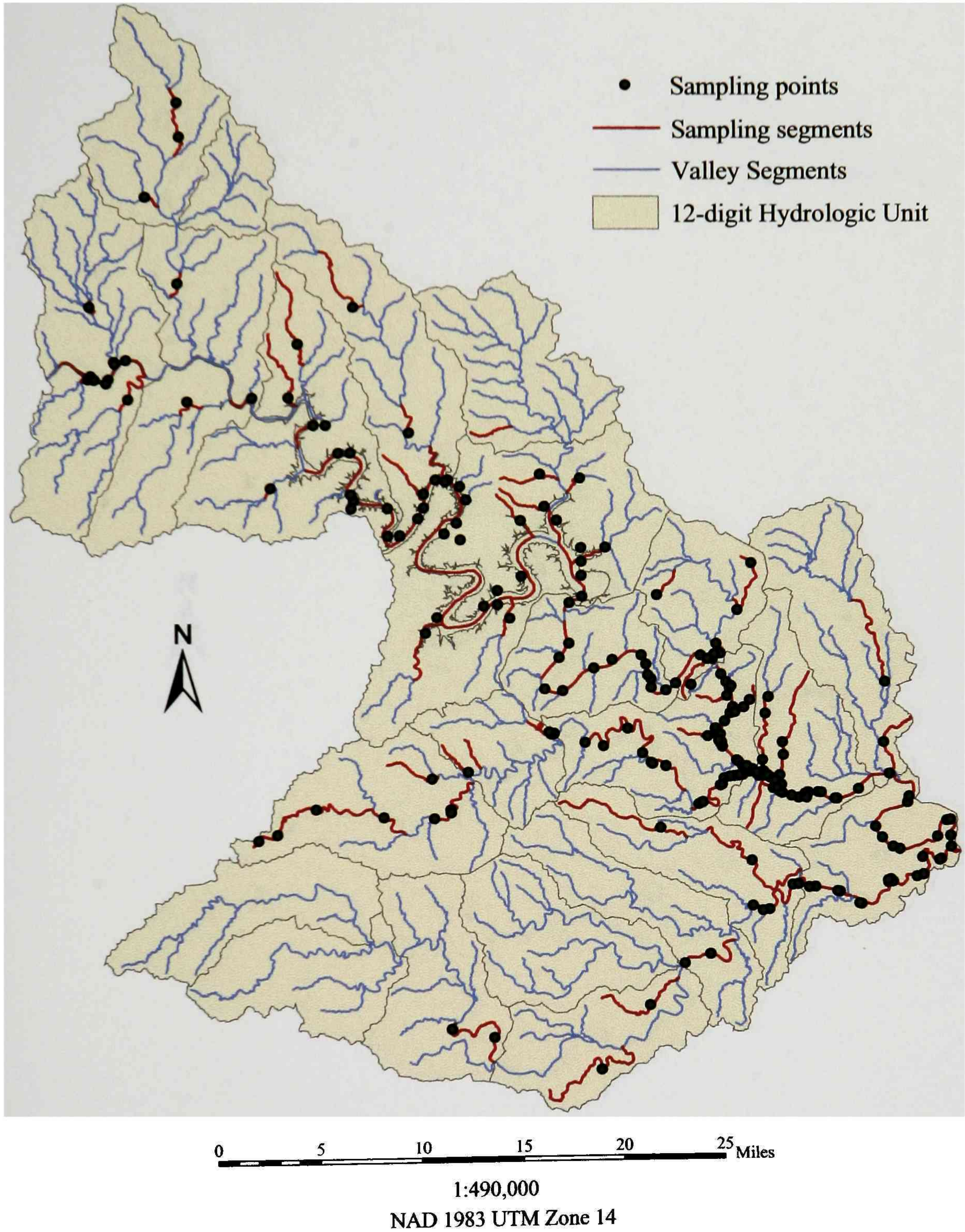

Figure 17. Sampling points and stream segments in the Hydrologic Unit 12090205 of Central Texas

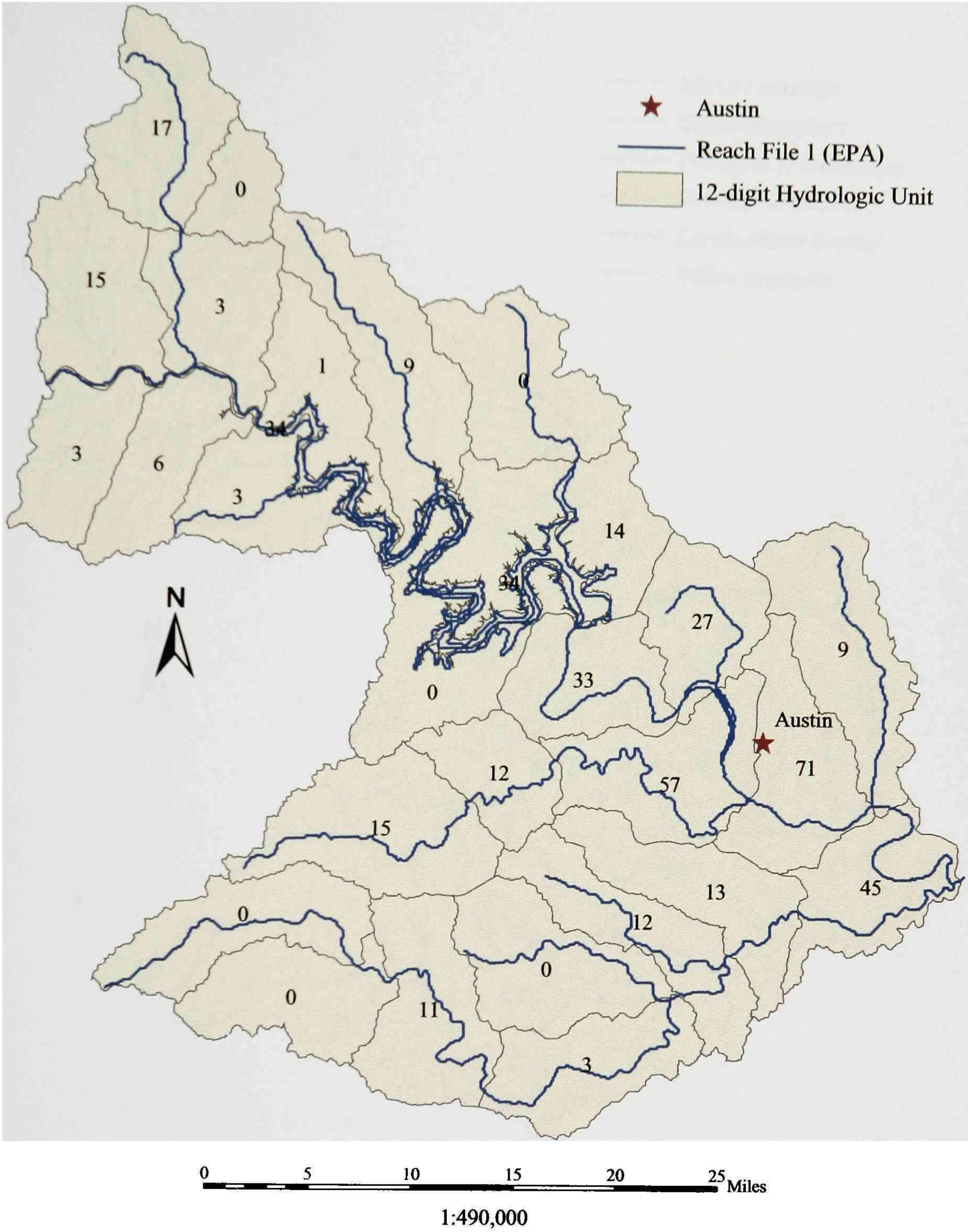

Figure 18. Number of speceis by 12-digit Hydrologic Unit in the 8-digit Hydrologic Unit 12090205 of Central Texas

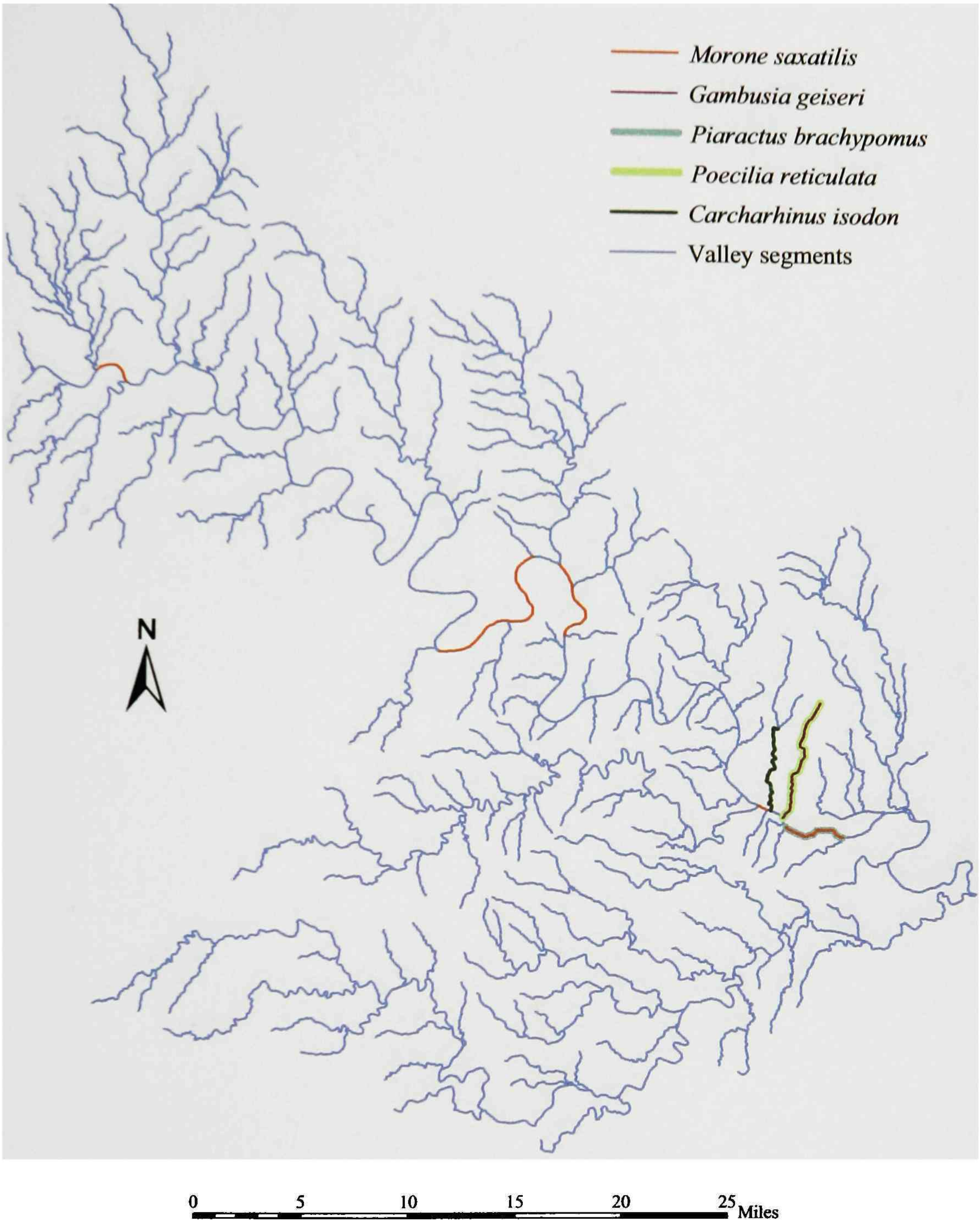

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Figure 19. Actual Occurrence map of species not predicted in the Hydrologic Unit 12090205 of Central Texas

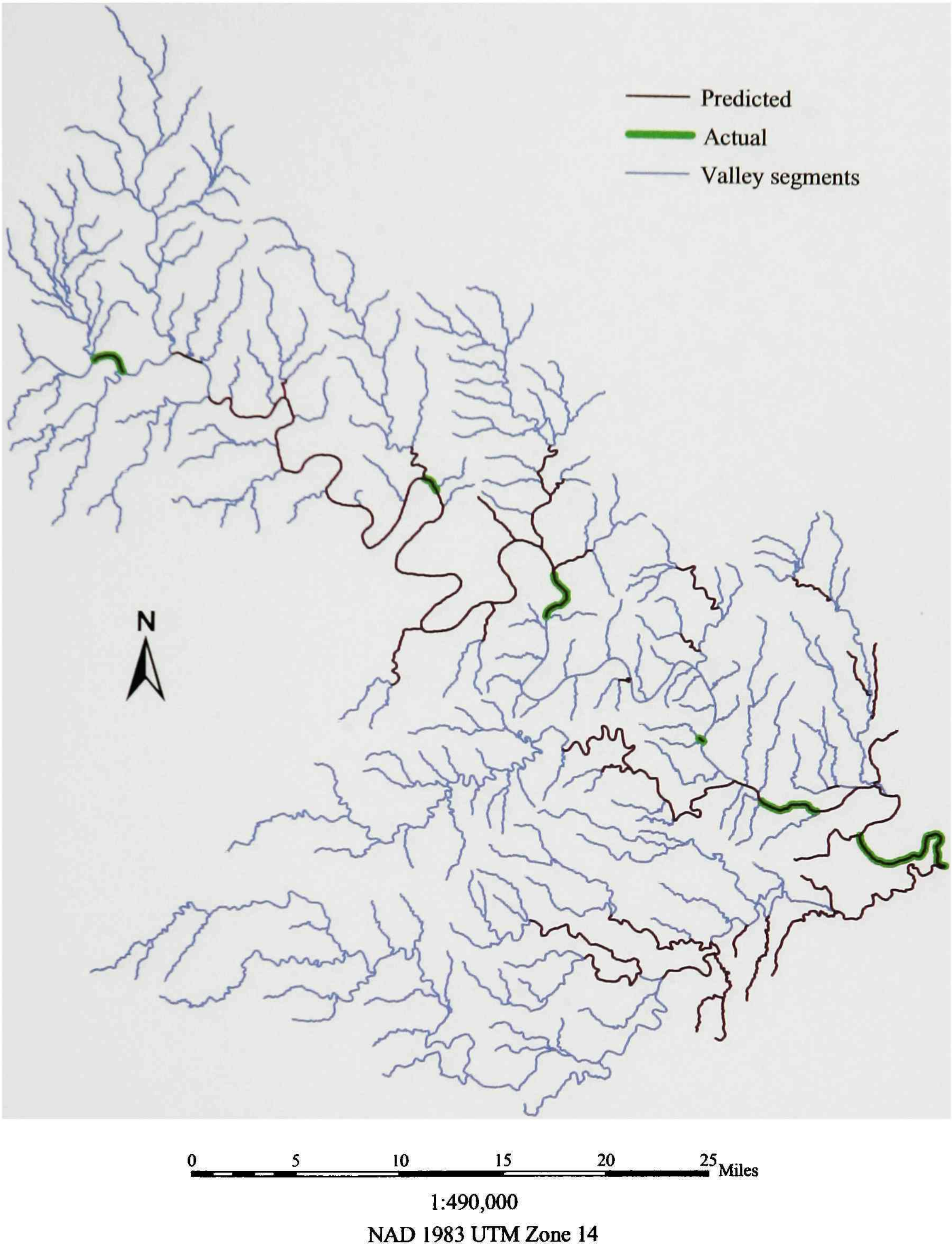

Figure 20. Species occurrence map: *Lepisosteus oculatus* in the Hydrologic Unit 12090205 of central Texas

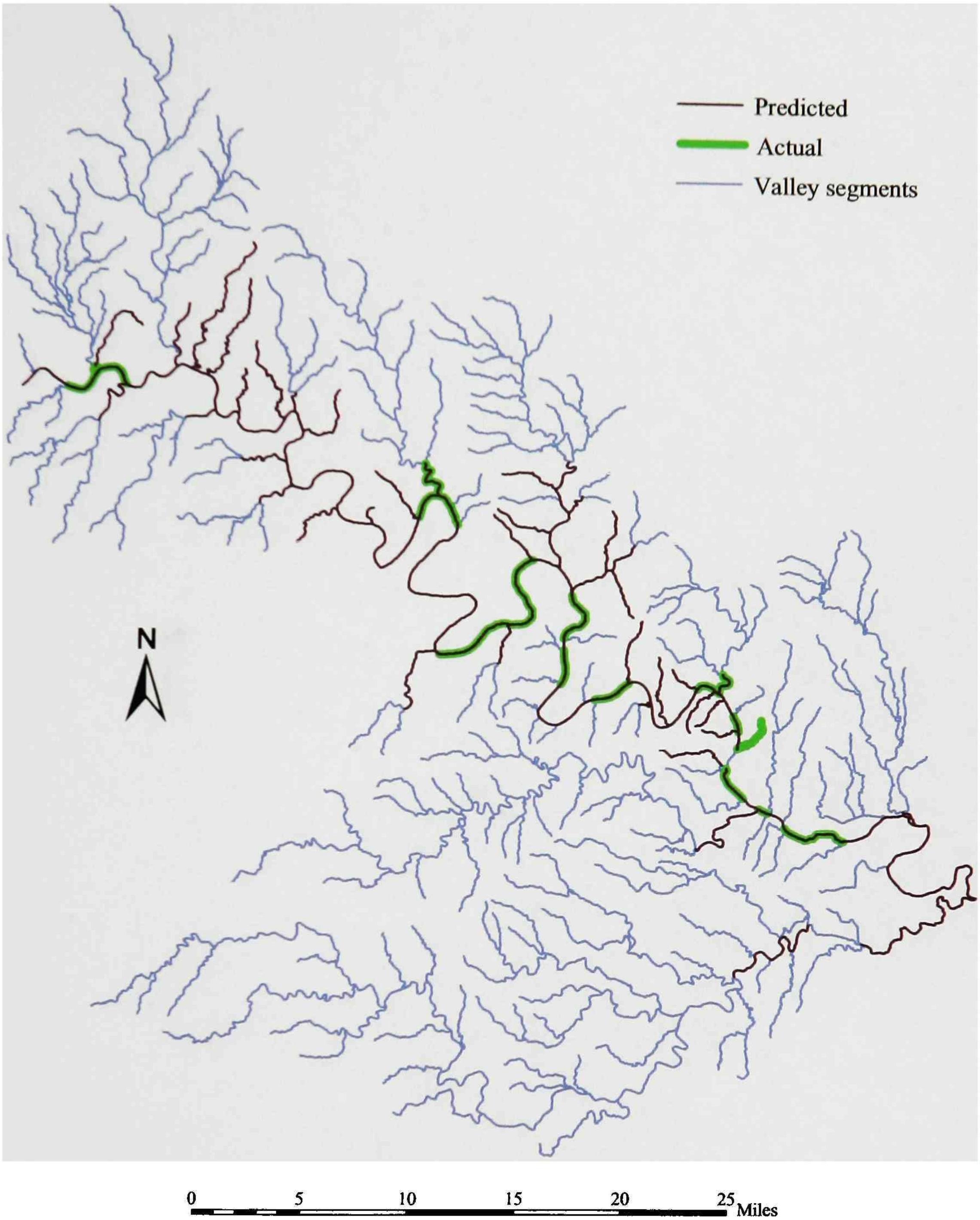

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Figure 21. Species occurrence map: *Lepisosteus osseus* in the Hydrologic Unit 12090205 of Central Texas

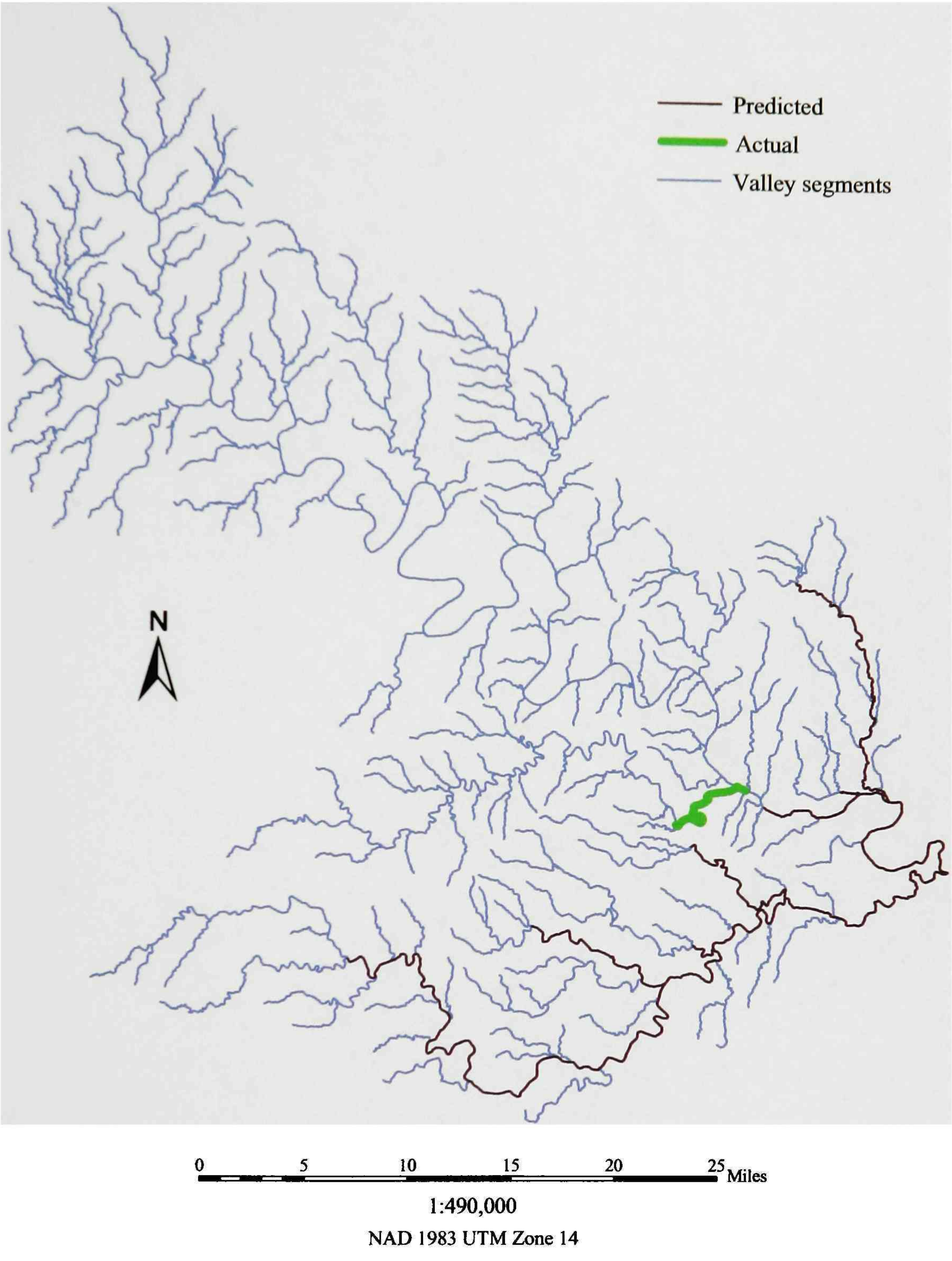

Figure 22. Species occurrence map: *Anguilla rostrata* in the Hydrologic Unit 12090205 of Central Texas

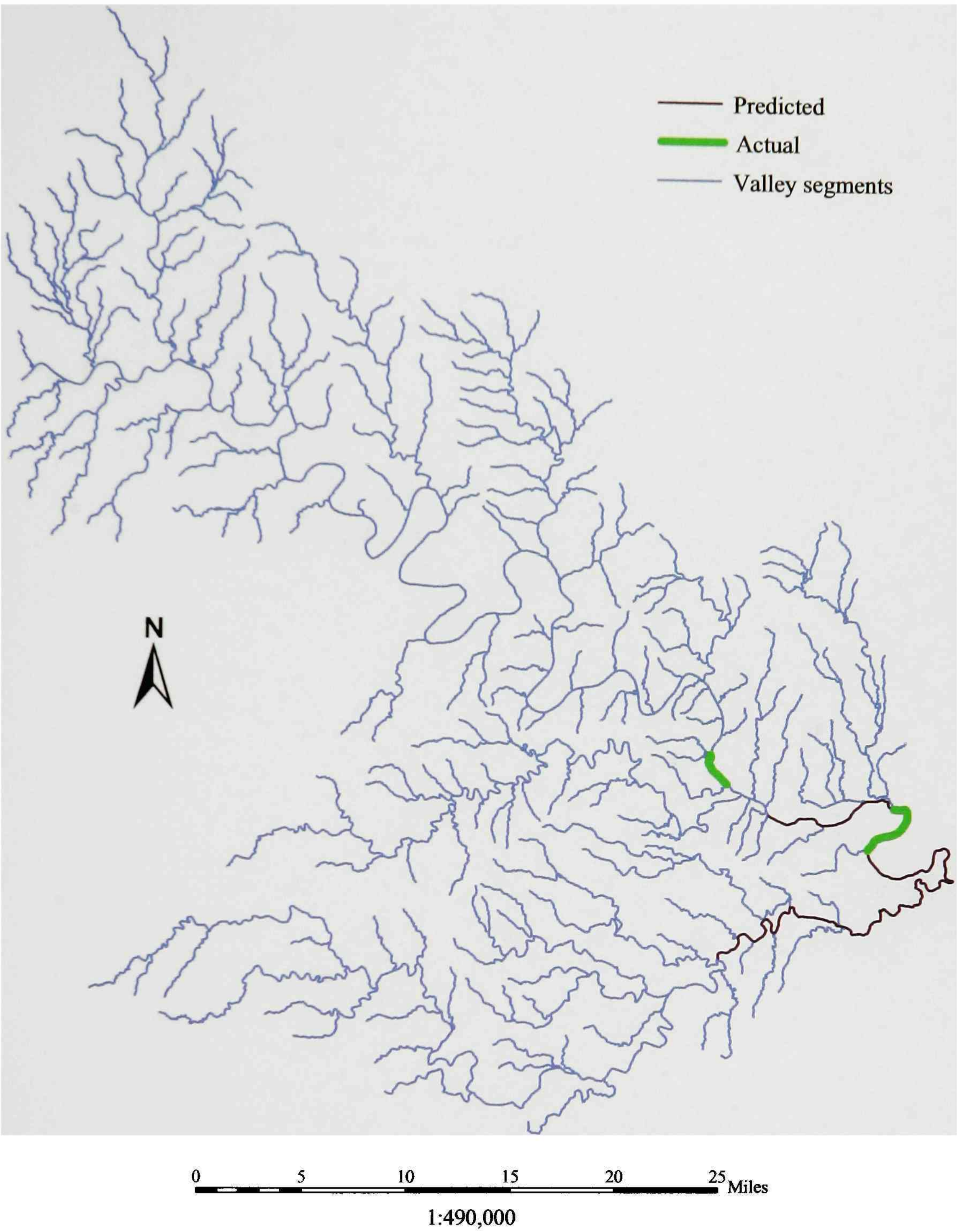

Figure 23. Species occurrence map: *Alosa chrysochloris* in the Hydrologic Unit 12090205 of Central Texas

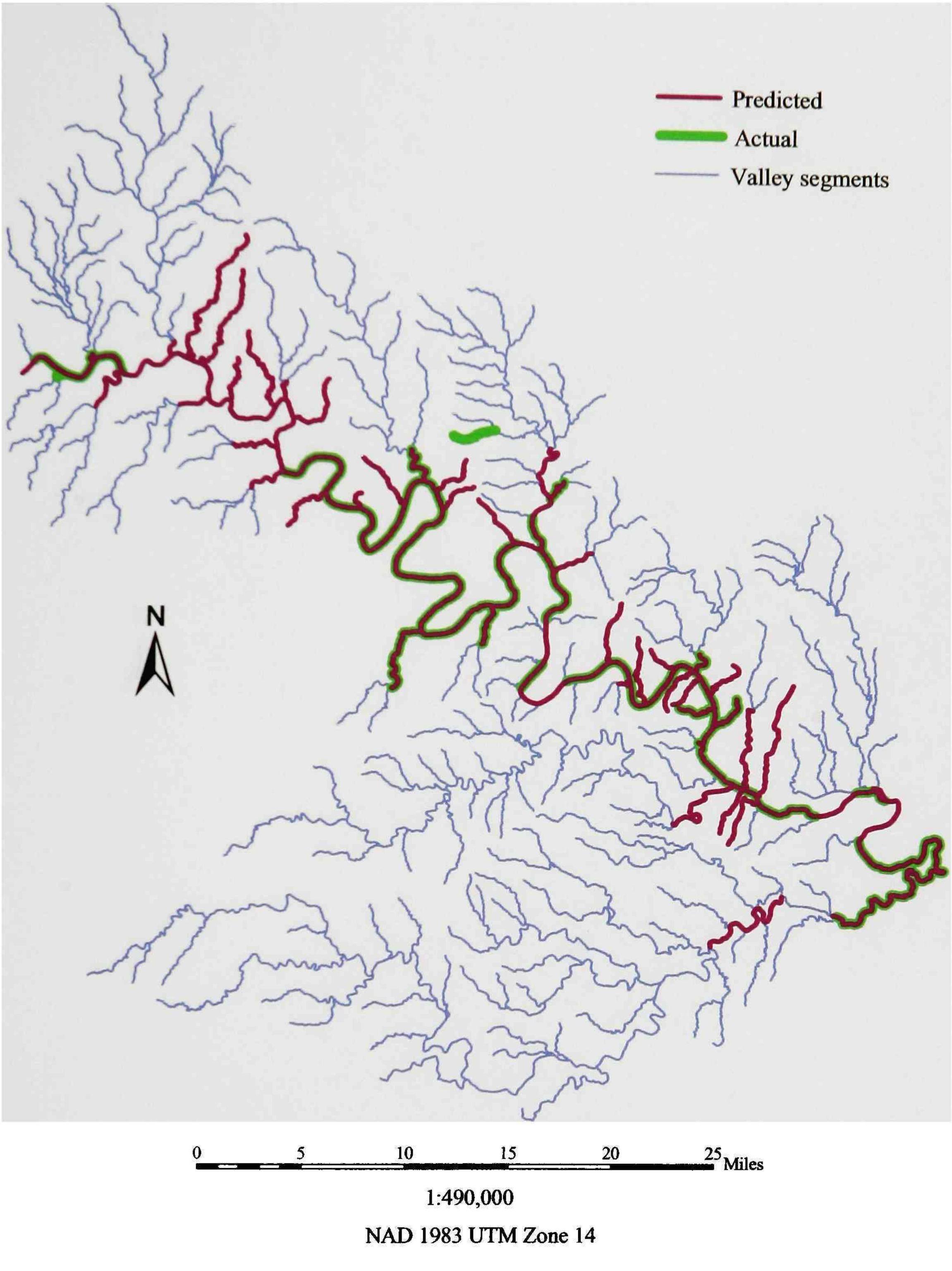

Figure 24. Species occurrence map: *Dorosoma cepedianum* in the Hydrologic Unit 12090205 of Central Texas

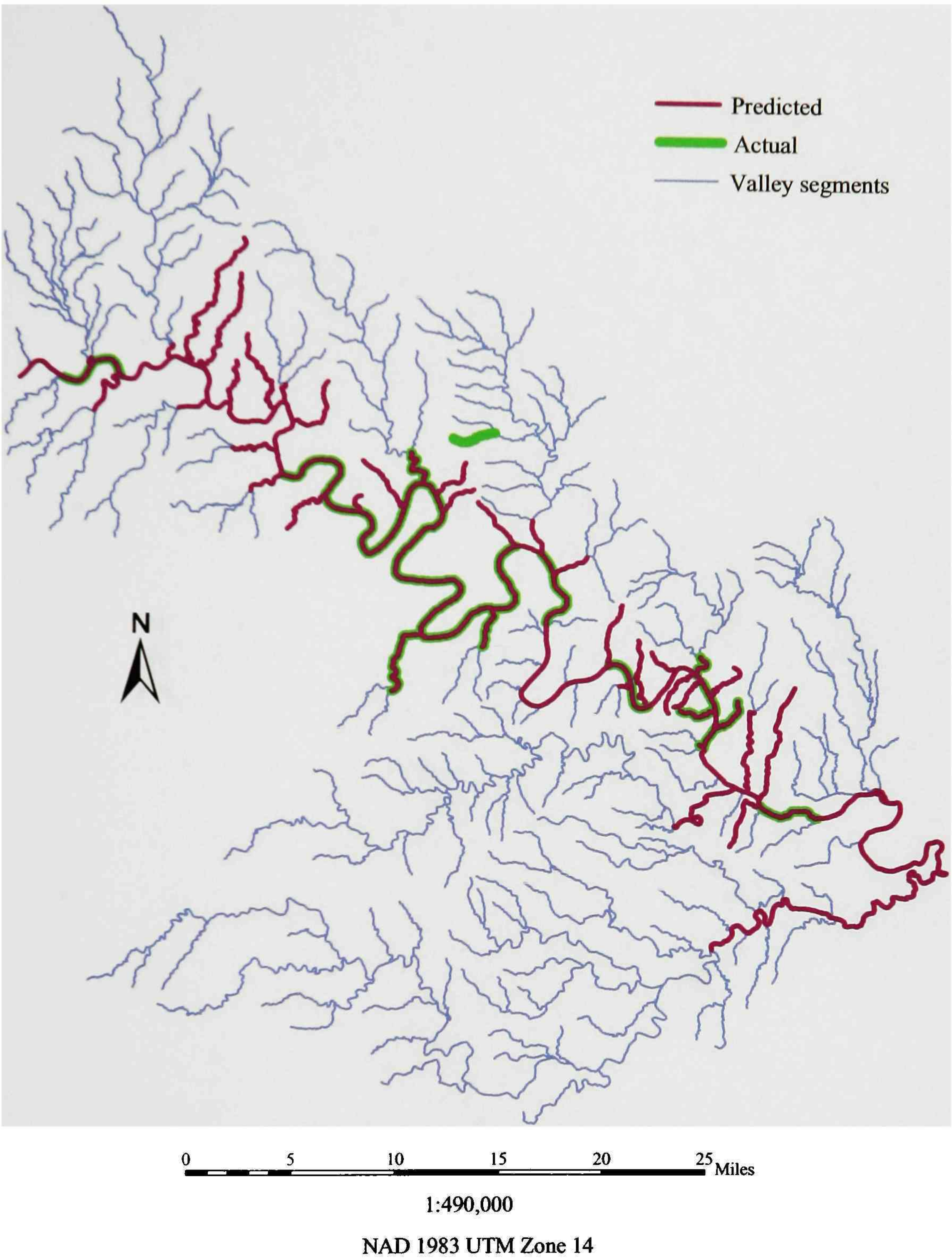

Figure 25. Species occurrence map: *Dorosoma petenense* in the Hydrologic Unit 12090205 of Central Texas

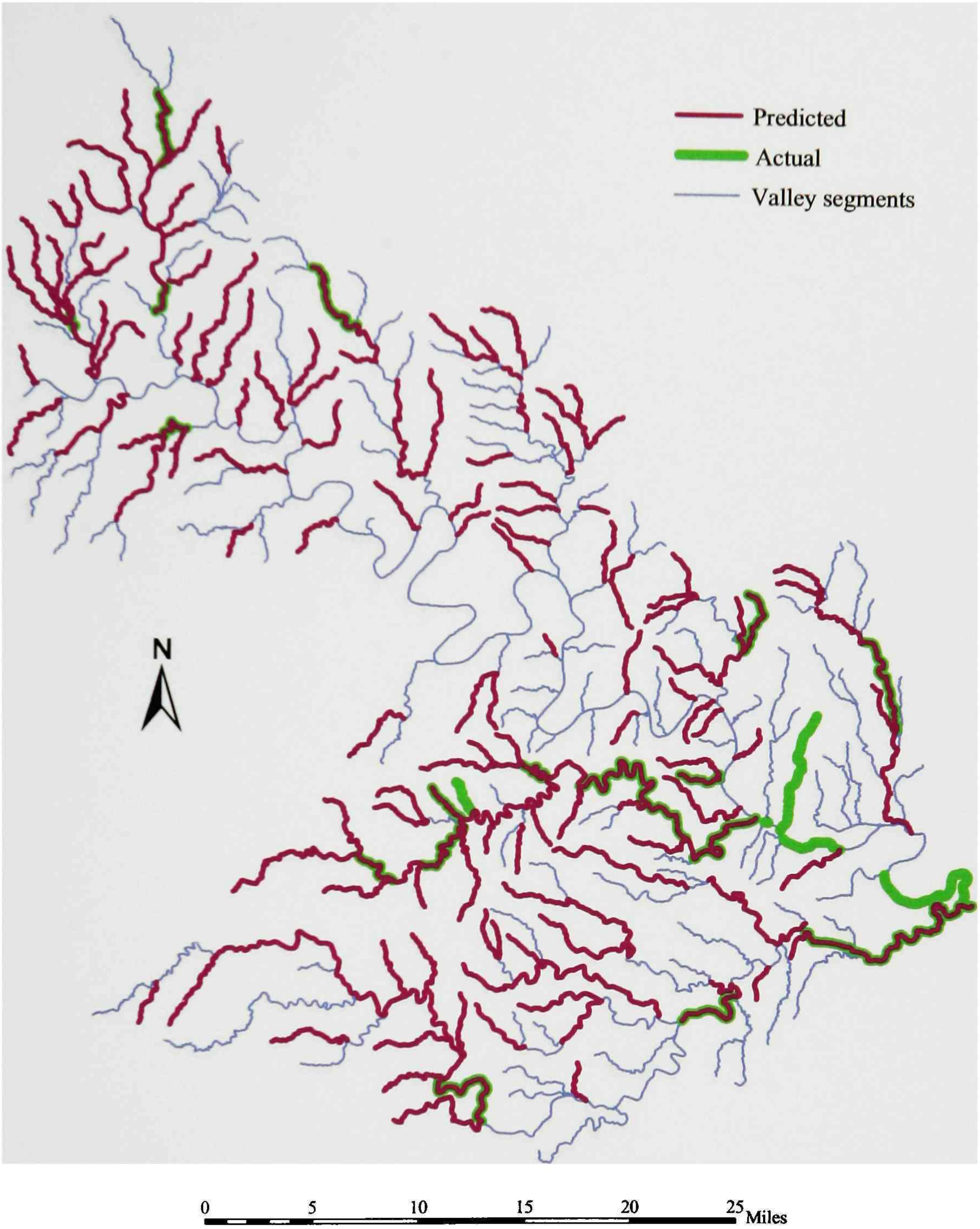

Figure 26. Species occurrence map: *Campostoma anomalum* in the Hydrologic Unit 12090205 of Central Texas

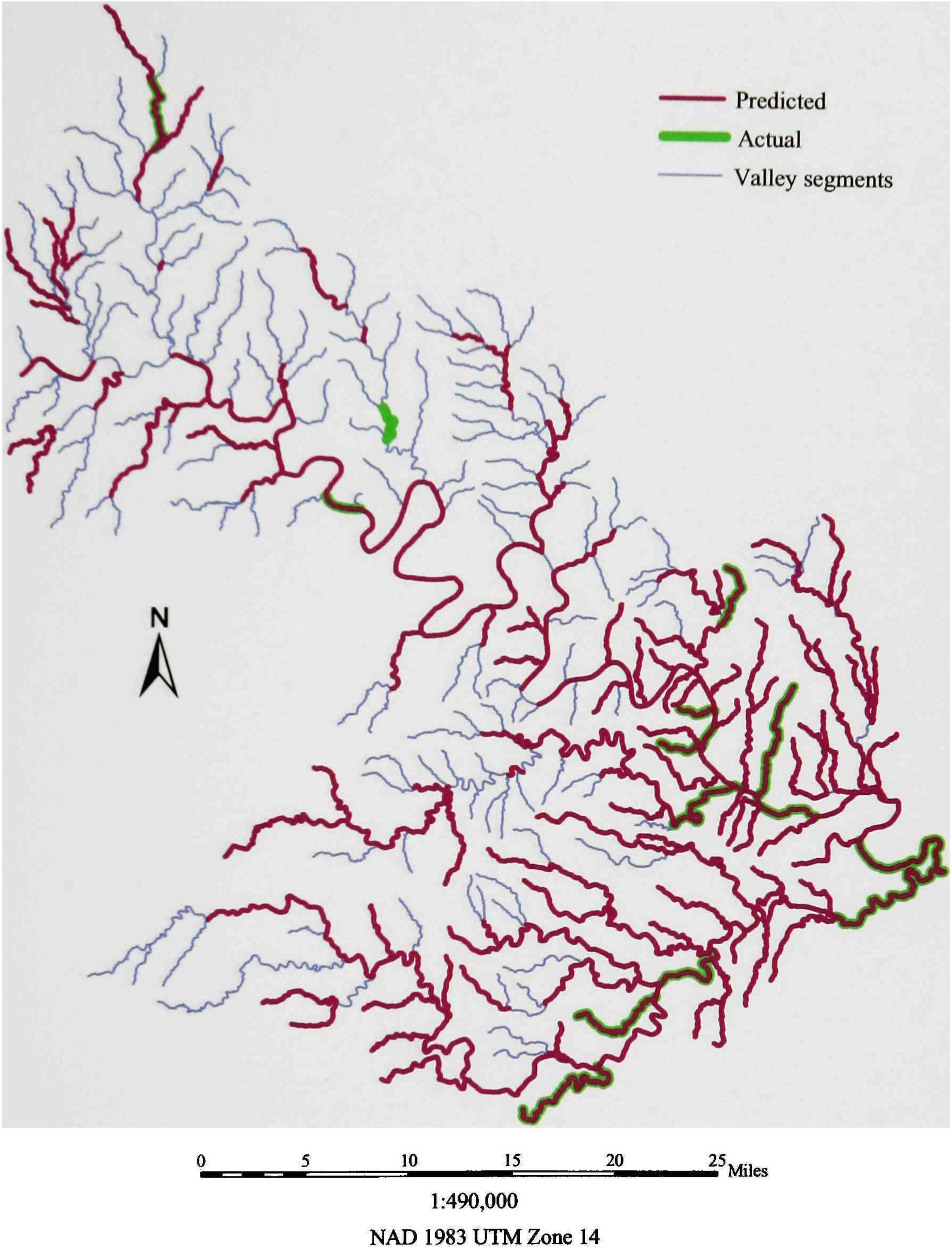

Figure 27. Species occurrence map: *Cyprinella lutrensis* in the Hydrologic Unit 12090205 of Central Texas

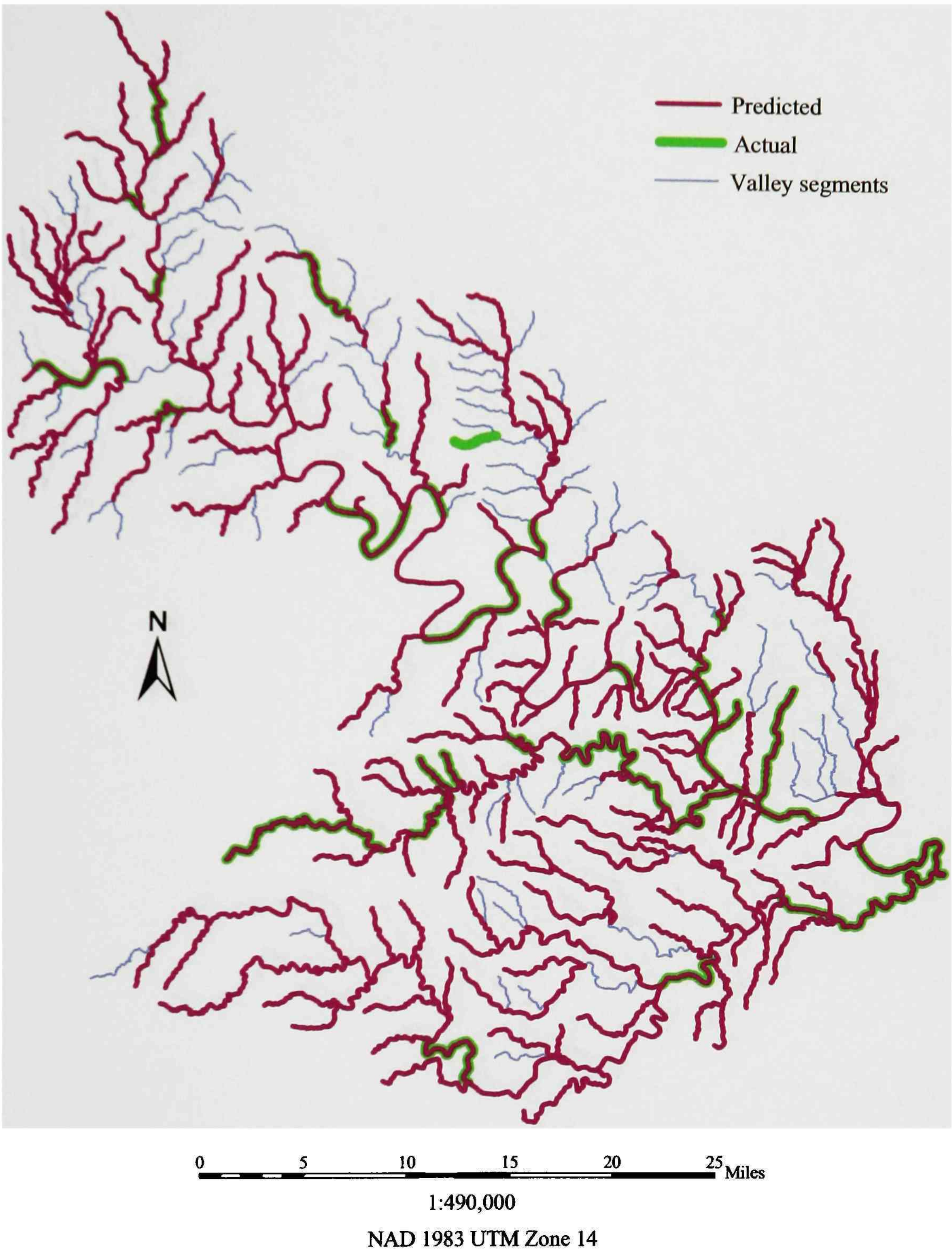

Figure 28. Species occurrence map: *Cyprinella venusta* in the Hydrologic Unit 12090205 of Central Texas

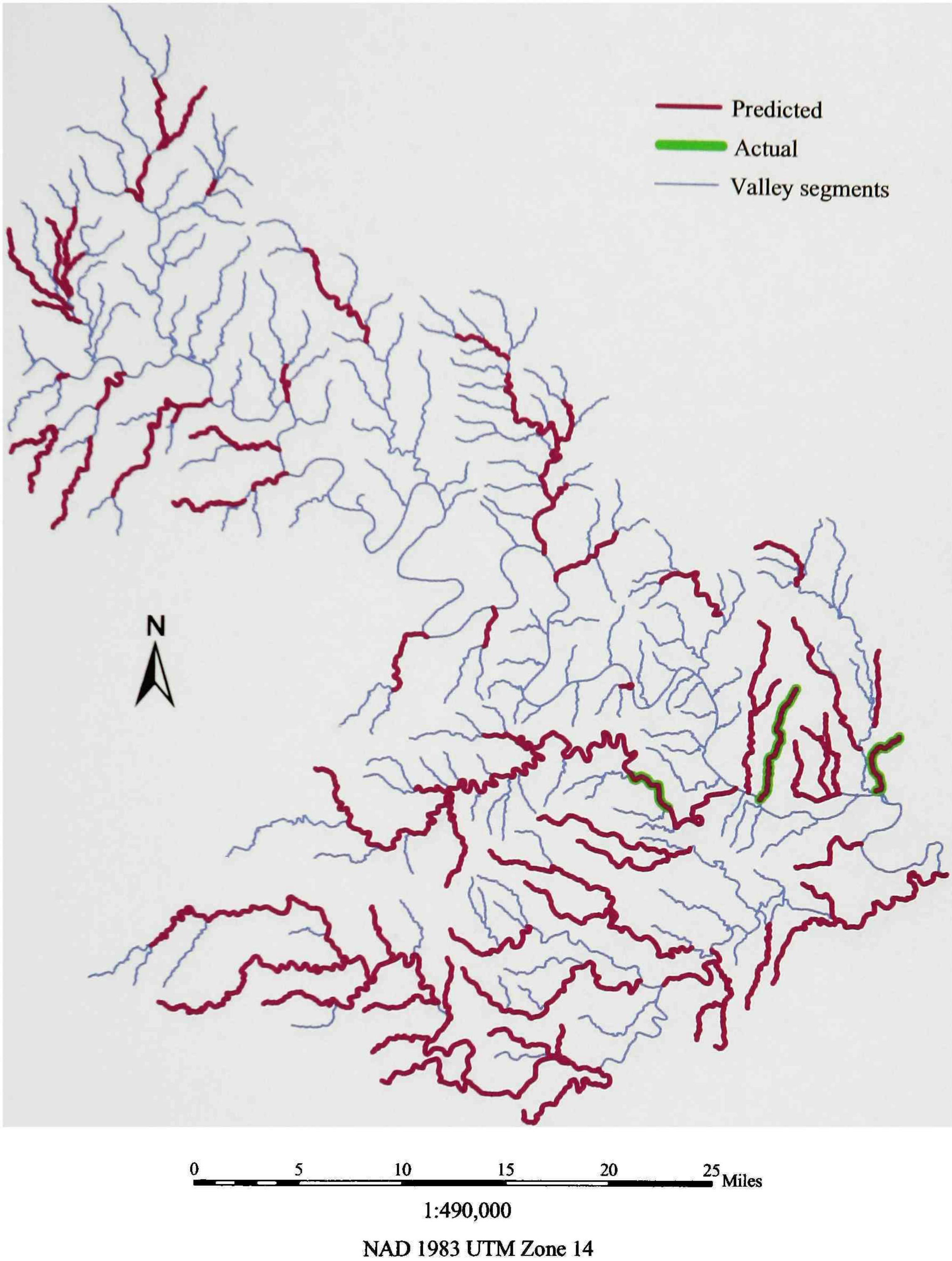

Figure 29. Species occurrence map: *Dionda episcopa* in the Hydrologic Unit 12090205 of Central Texas

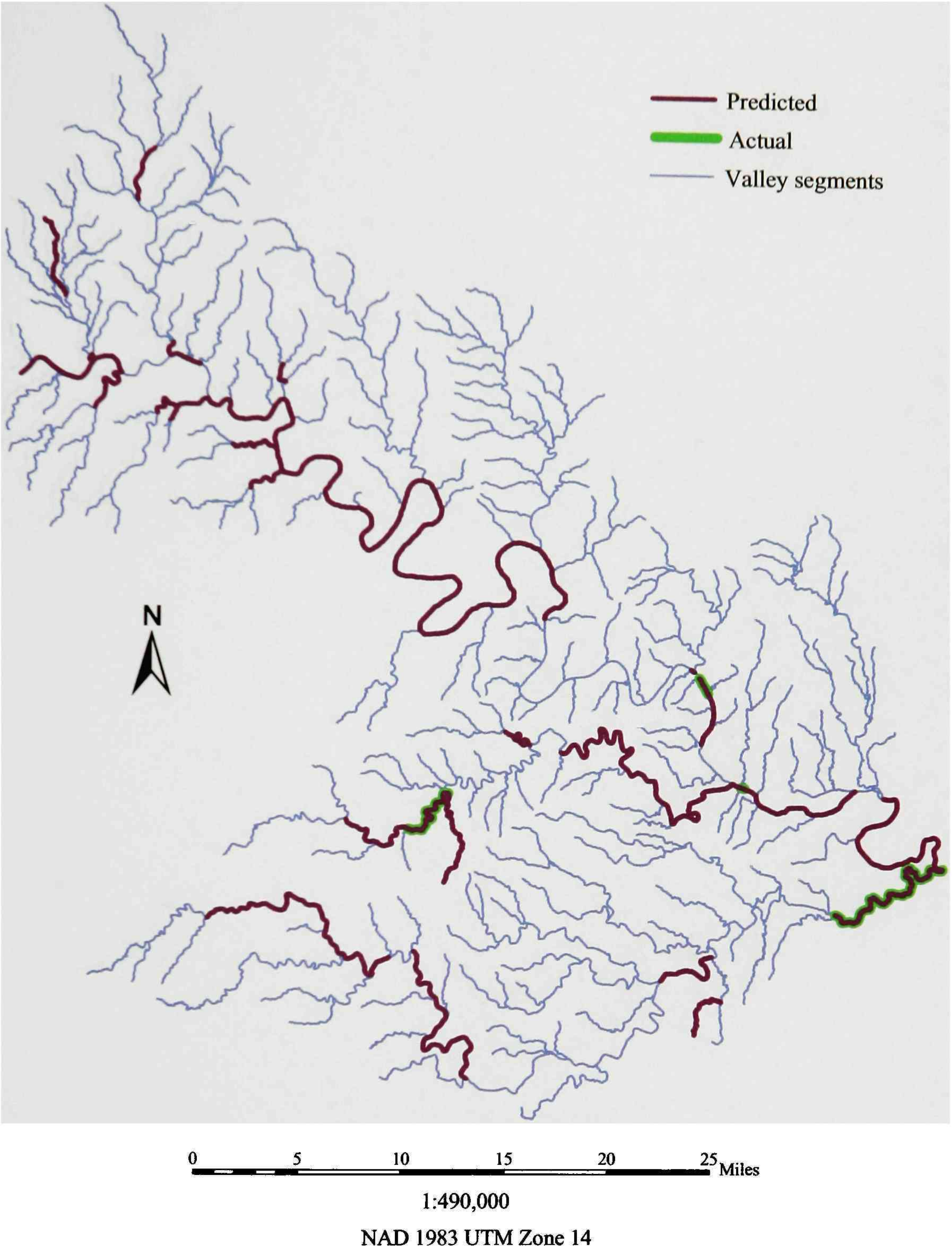

Figure 30. Species occurrence map: *Hybopsis amnis* in the Hydrologic Unit 12090205 of Central Texas

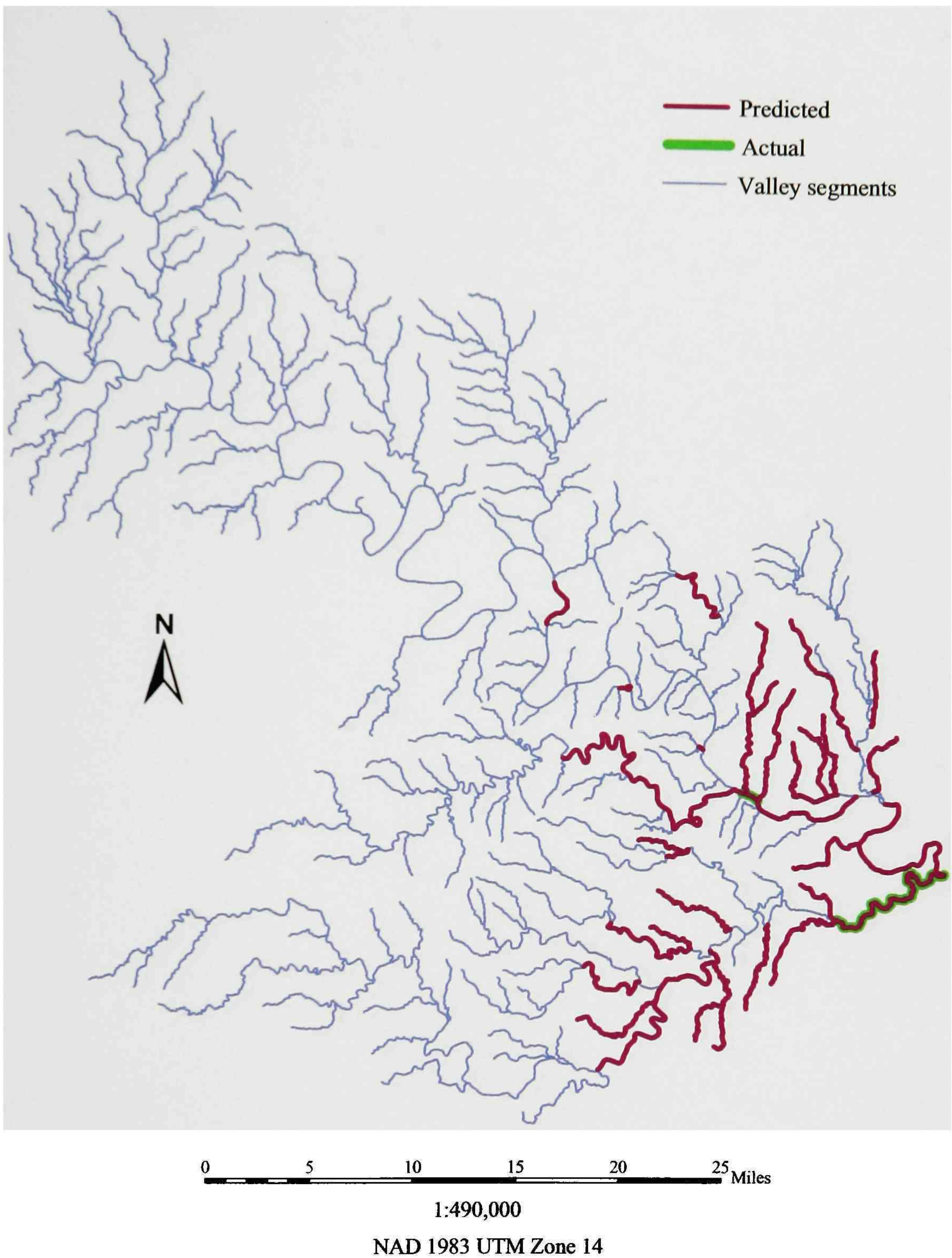

Figure 31. Species occurrence map: *Lythrurus fumeu* in the Hydrologic Unit 12090205 of Central Texas

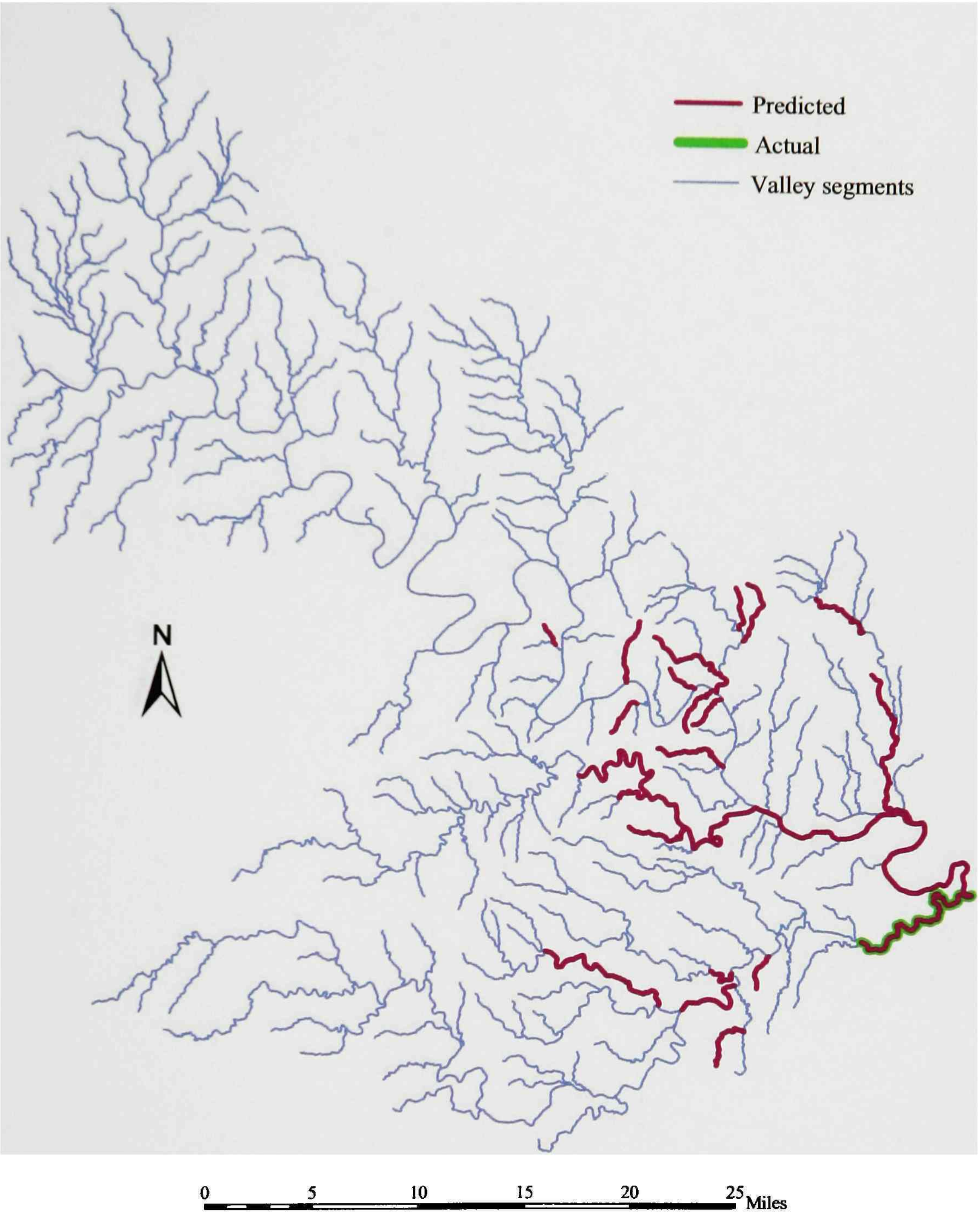

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Figure 32. Species occurrence map: *Lythrurus umbratilis* in the Hydrologic Unit 12090205 of central Texas

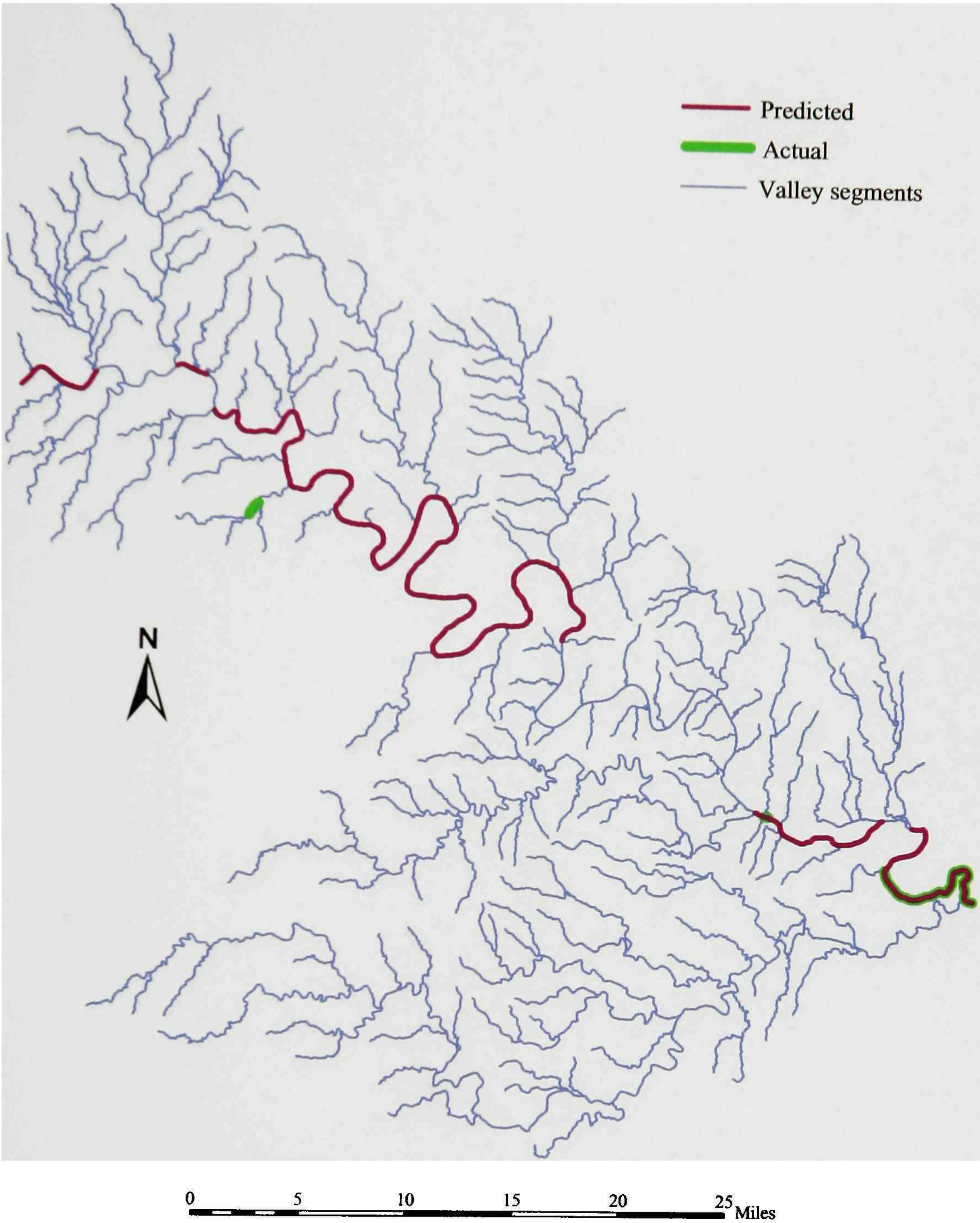

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Figure 33. Species occurrence map: *Macrhybopsis aestvalis* in the Hydrologic Unit 12090205 of Central Texas

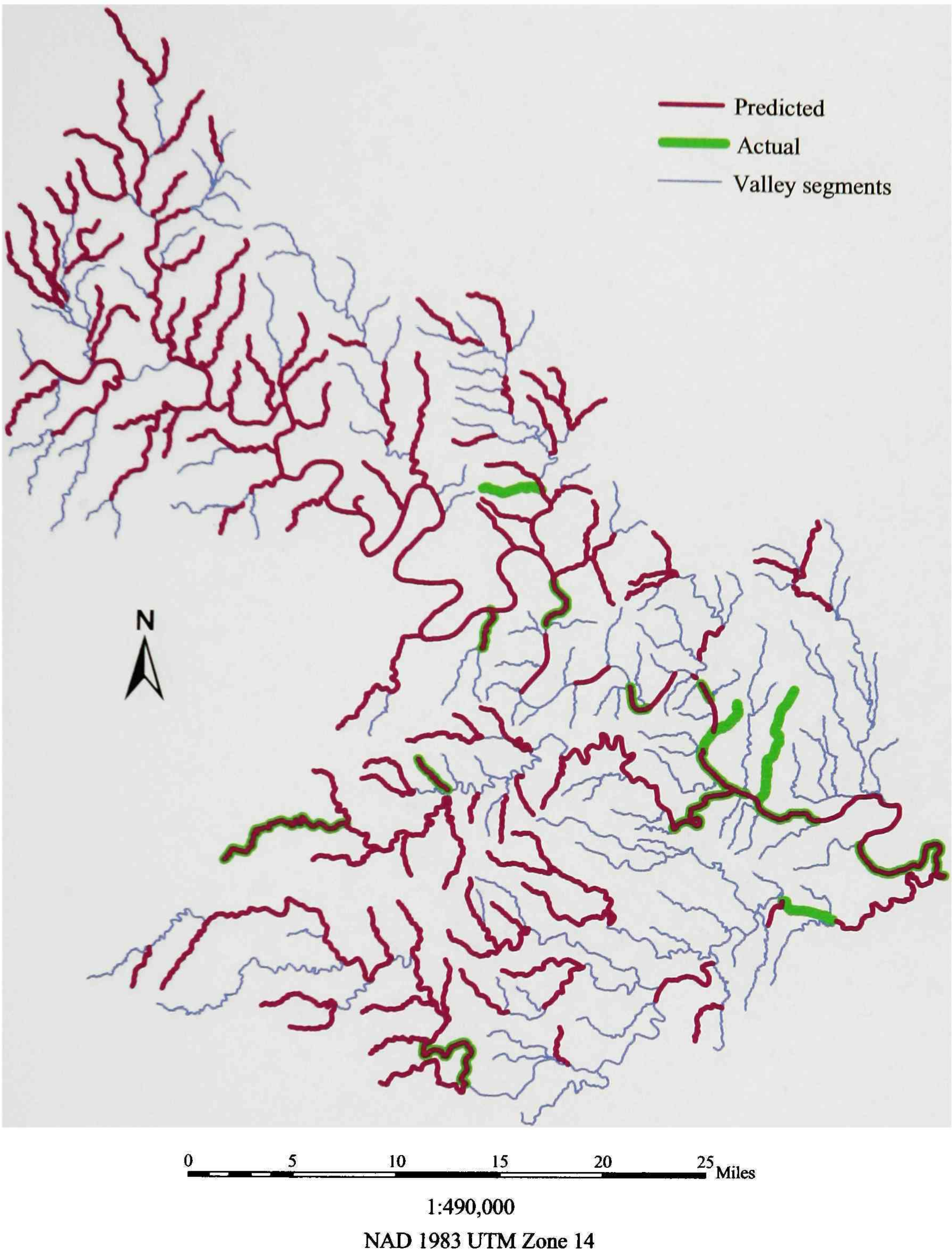

Figure 34. Species occurrence map: *Notemigonus crysoleucas* in the Hydrologic Unit 12090205 of Central Texas

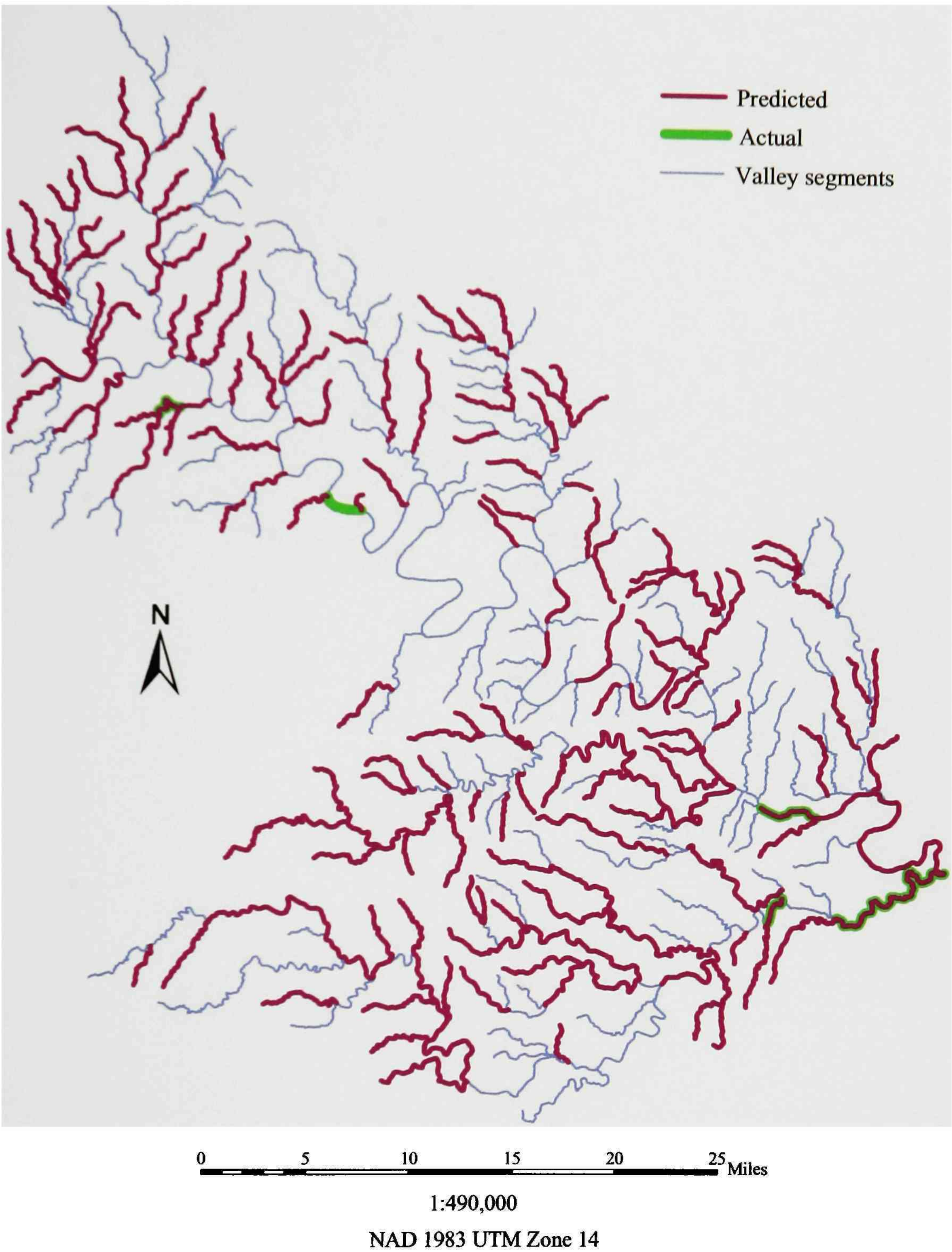

Figure 35. Species occurrence map: *Notropis amabilis* in the Hydrologic Unit 12090205 of Central Texas

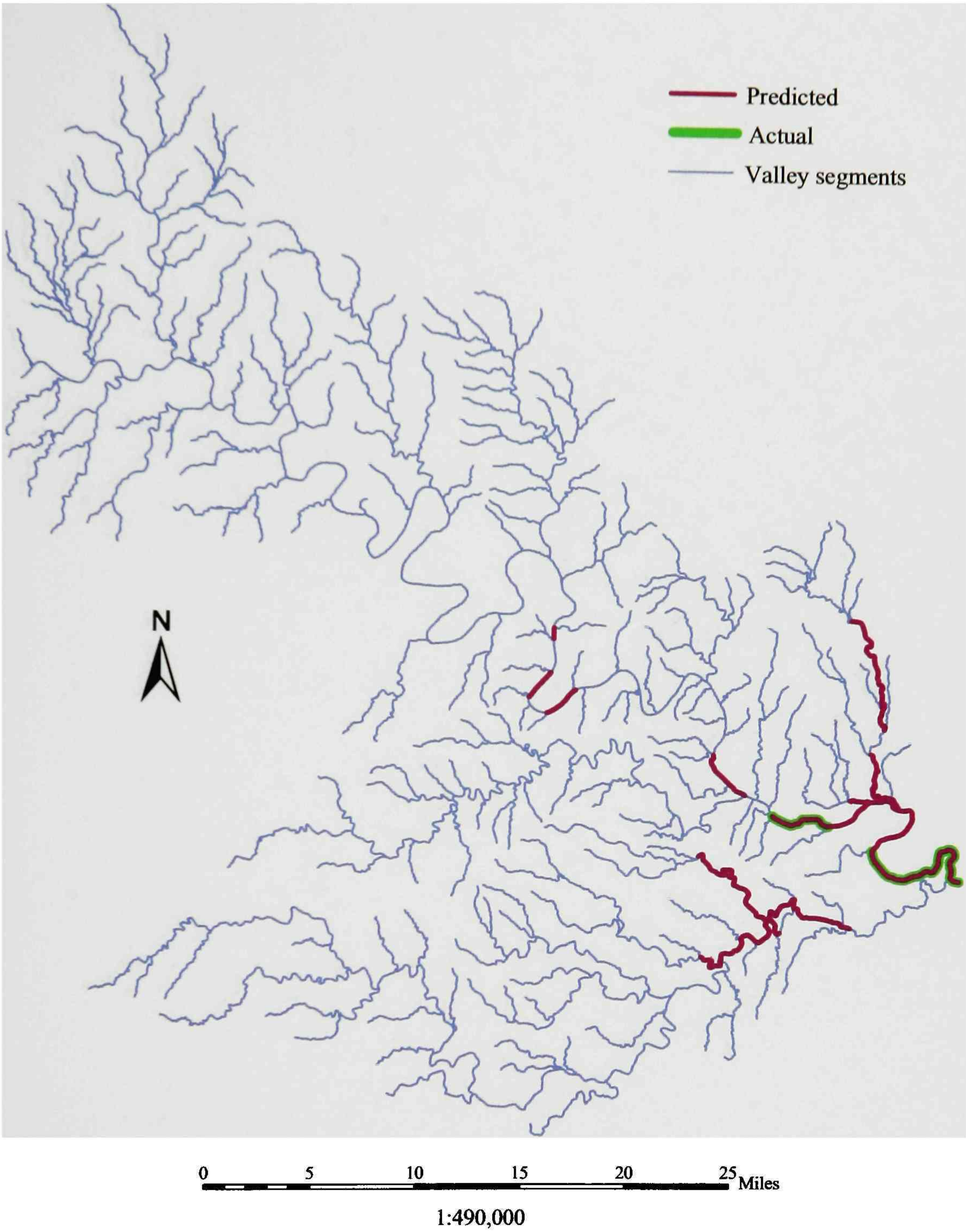

Figure 36. Species occurrence map: *Notropis buccula* in the Hydrologic Unit 12090205 of Central Texas

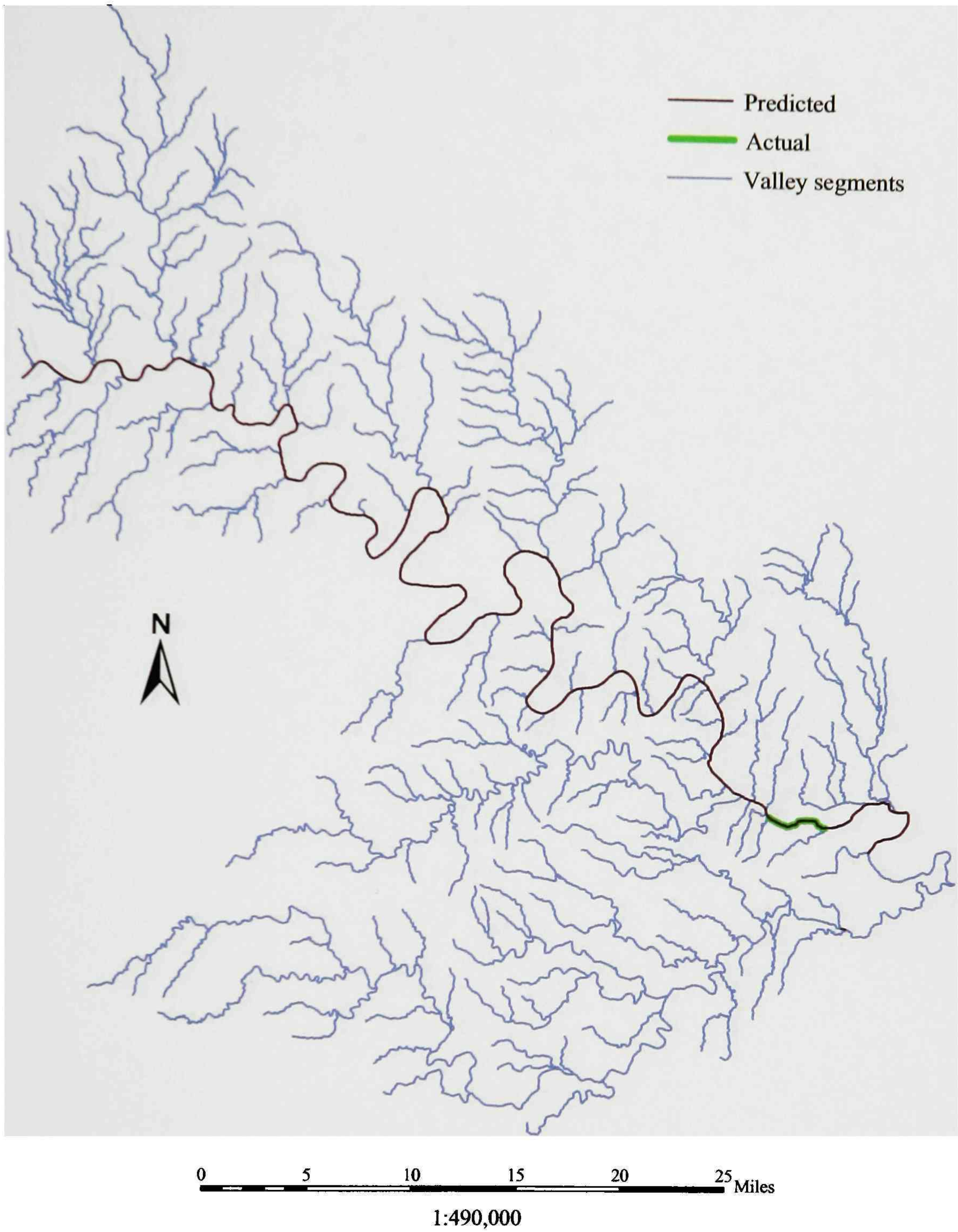

Figure 37. Species occurrence map: *Notropis oxyrhynchus* in the Hydrologic Unit 12090205 of Central Texas

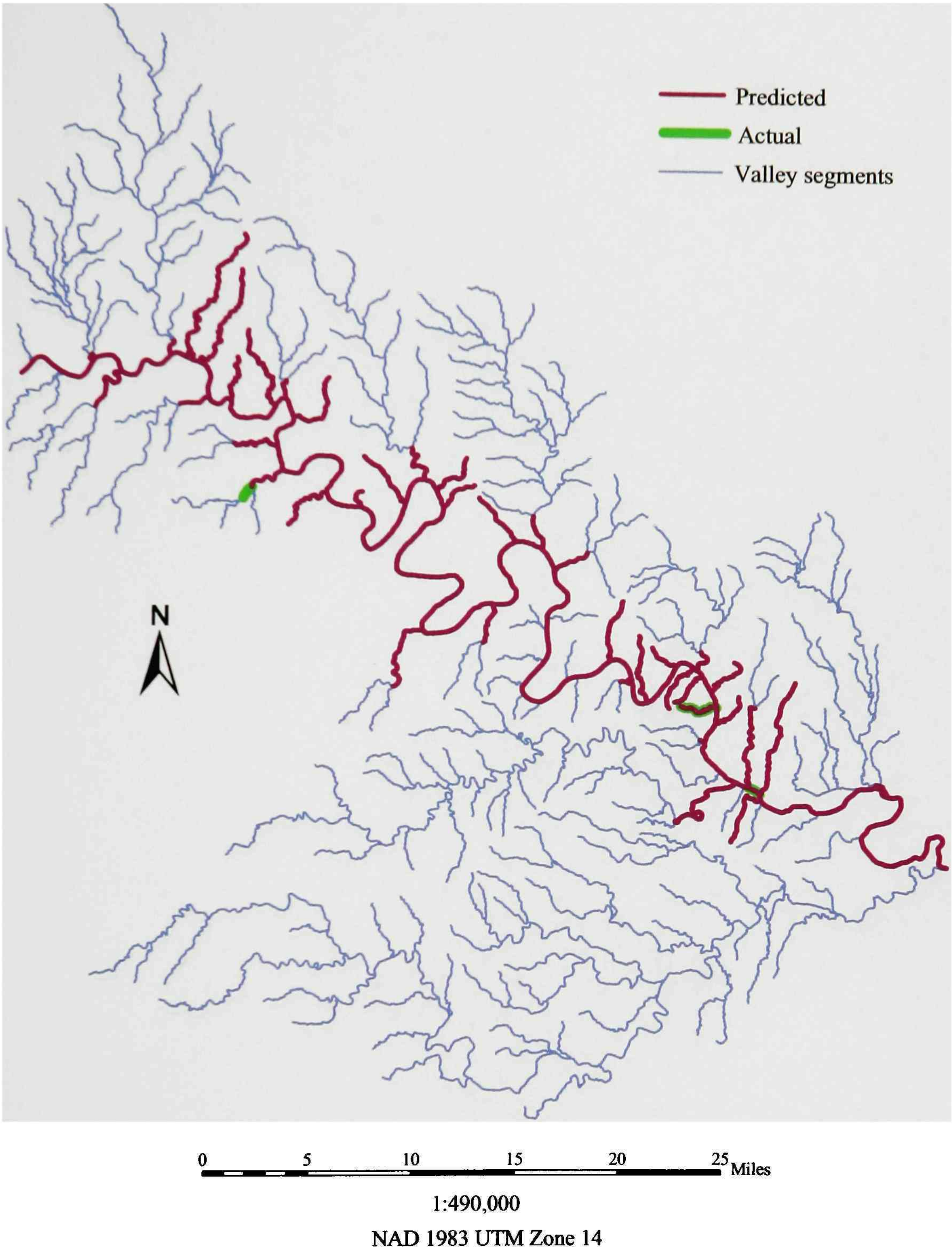

Figure 38. Species occurrence map: *Notropis shumardi* in the Hydrologic Unit 12090205 of Central Texas

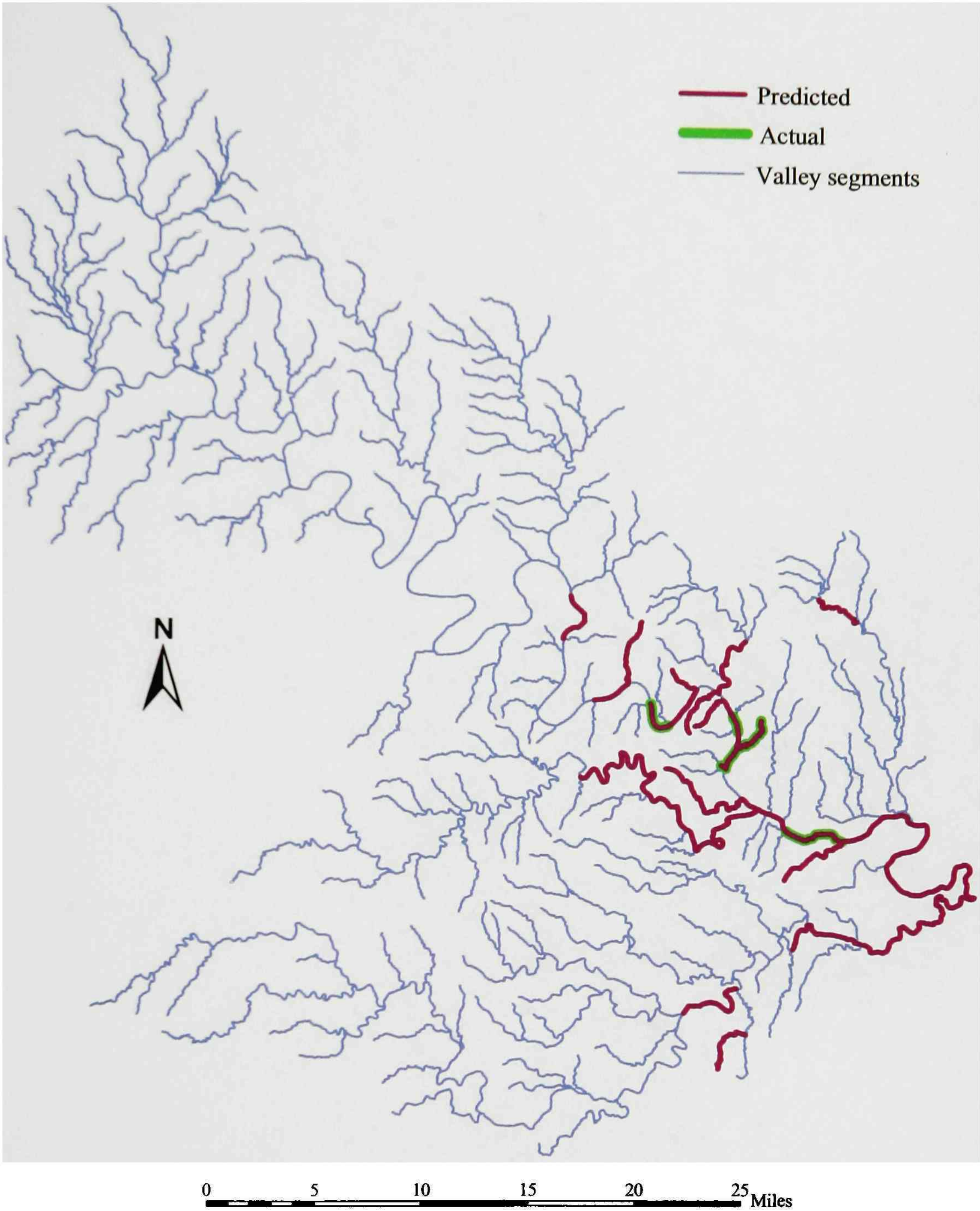

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Figure 39. Species occurrence map: *Notropis stramineus*in the Hydrologic Unit 12090205 of Central Texas

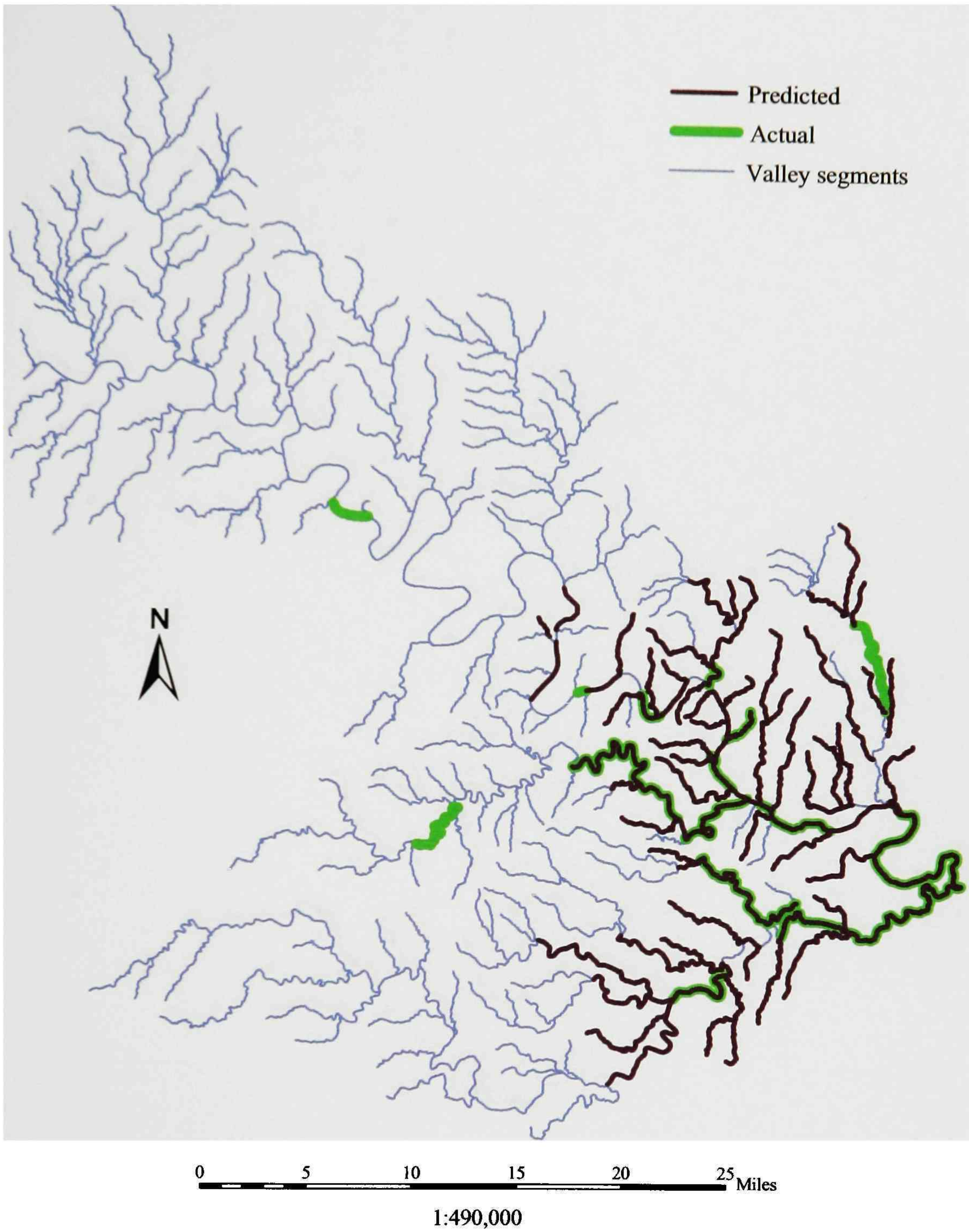

Figure 40. Species occurrence map: *Notropis texanus* in the Hydrologic Unit 12090205 of Central Texas

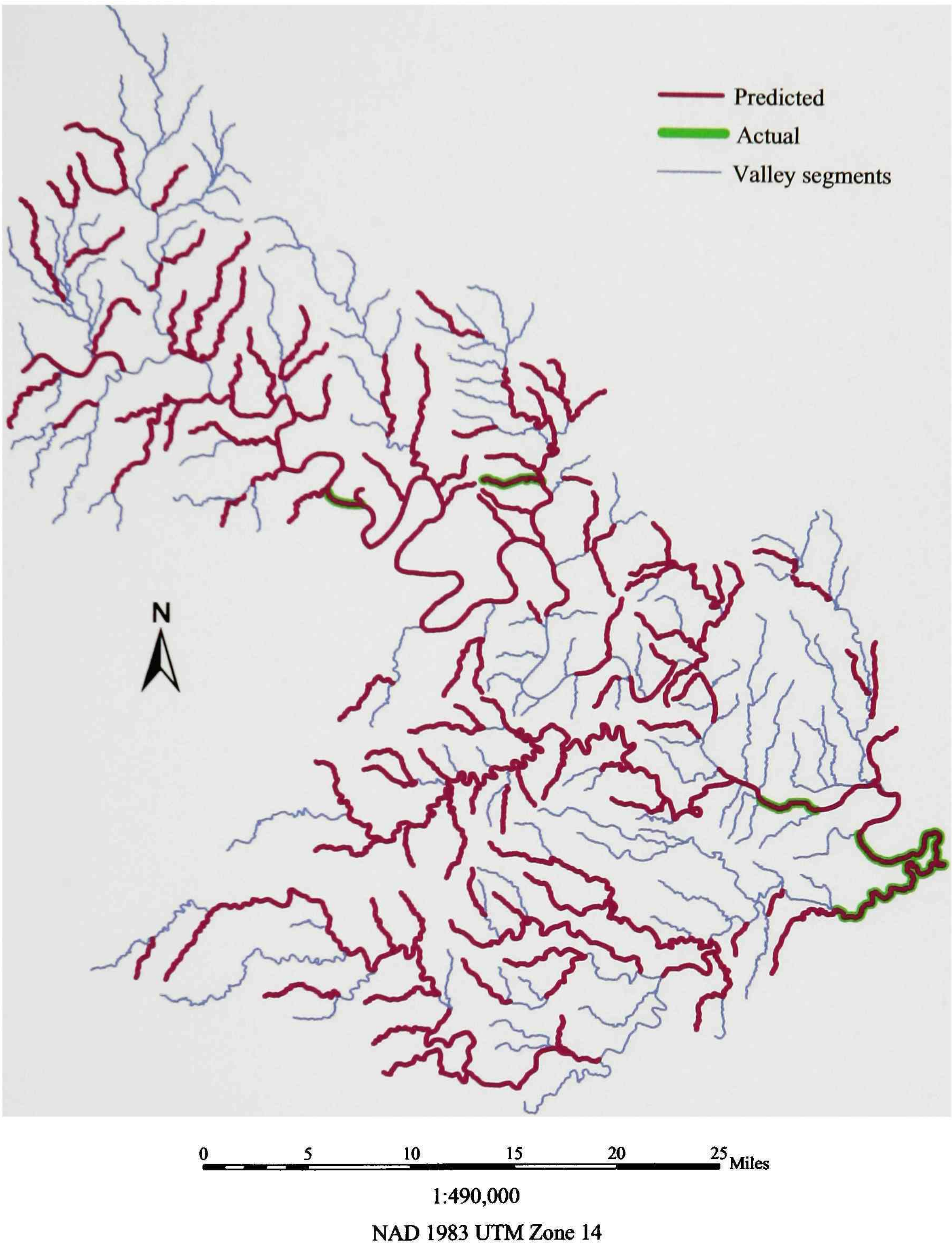

Figure 41. Species occurrence map: *Notropis volucellus* in the Hydrologic Unit 12090205 of Central Texas

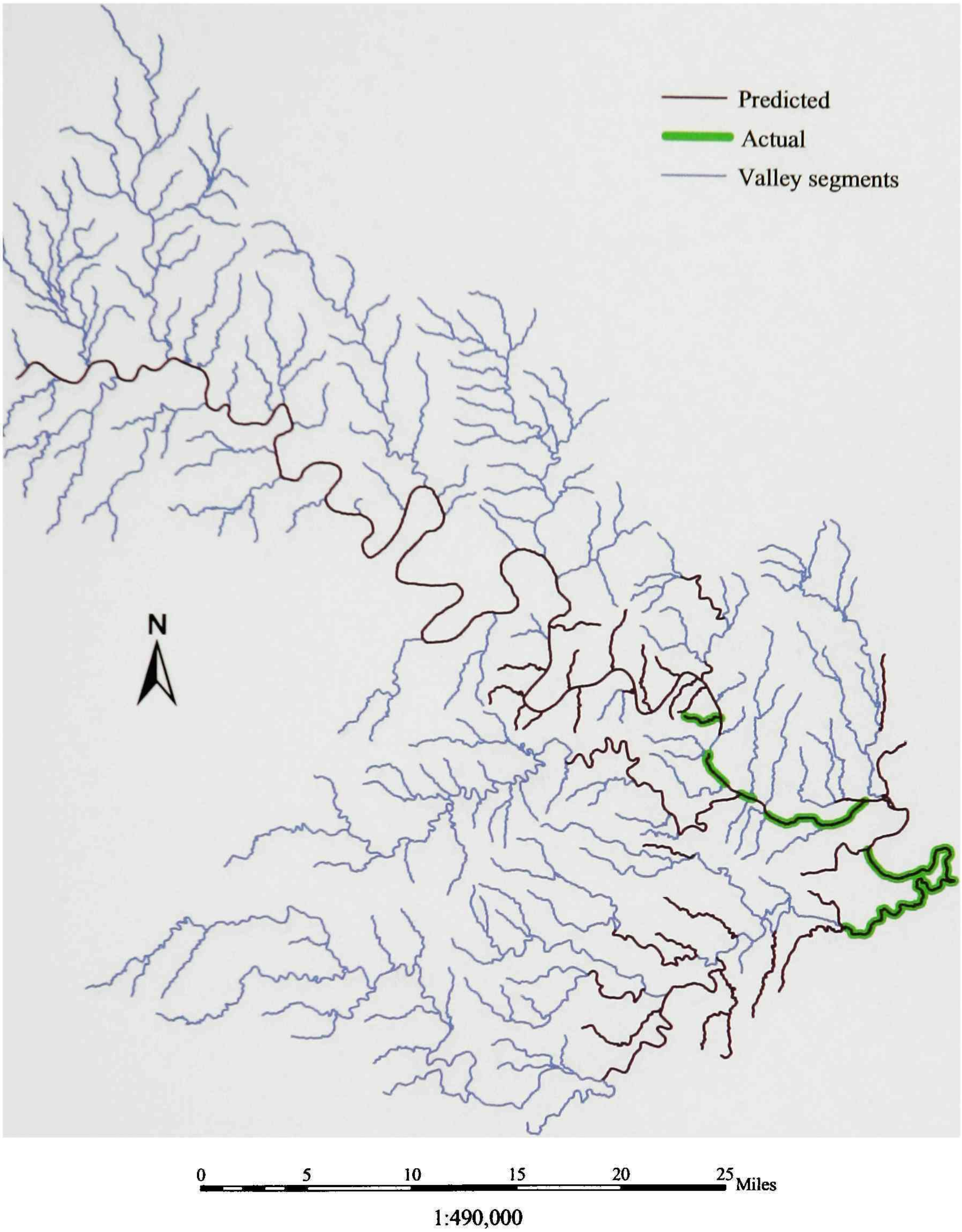

Figure 42. Species occurrence map: *Opsopoeodus emiliae* in the Hydrologic Unit 12090205 of Central Texas

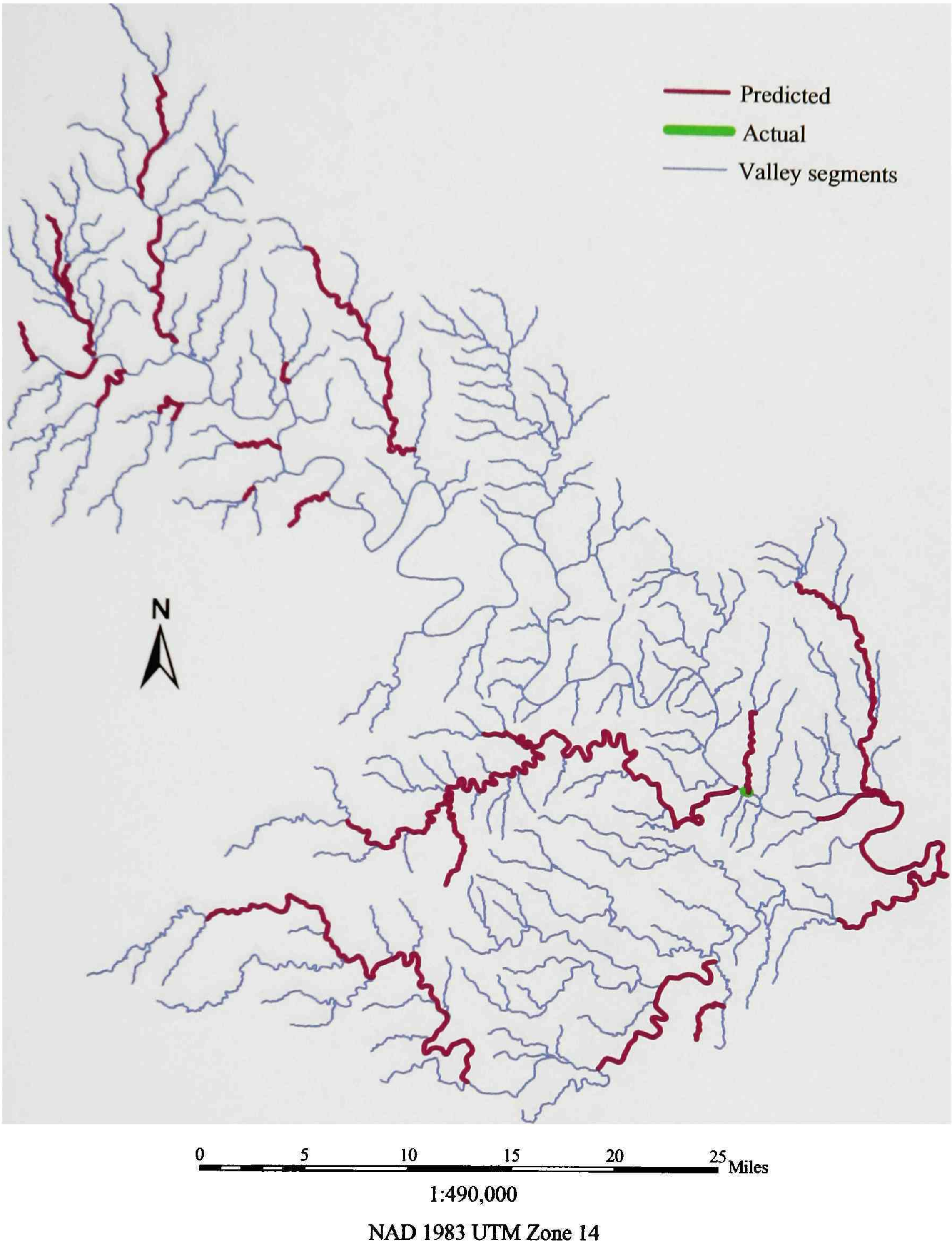

Figure 43. Species occurrence map: *Phenacobius mirabilis* in the Hydrologic Unit 12090205 of Central Texas

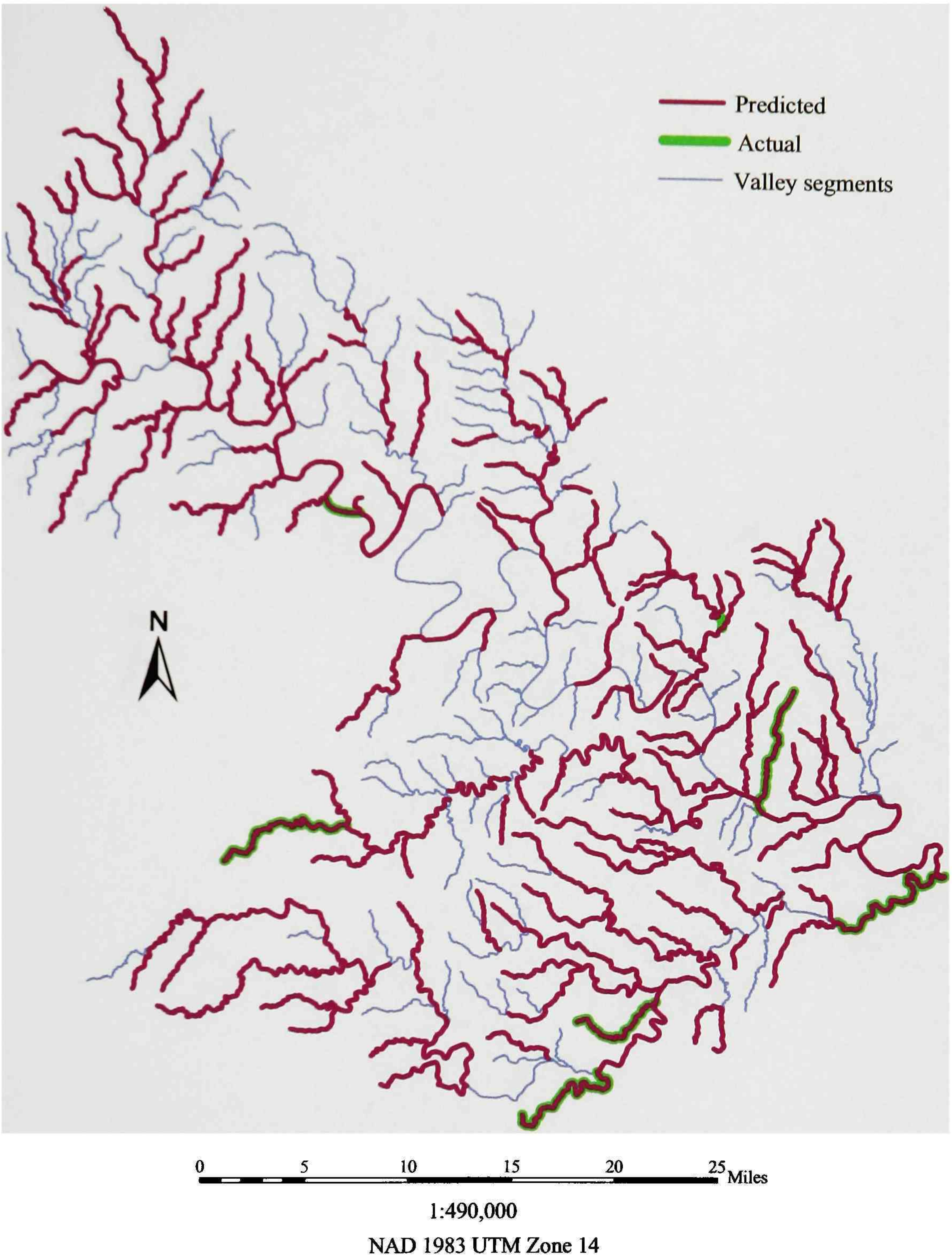

Figure 44. Species occurrence map: *Pimephales promelas* in the Hydrologic Unit 12090205 of Central Texas

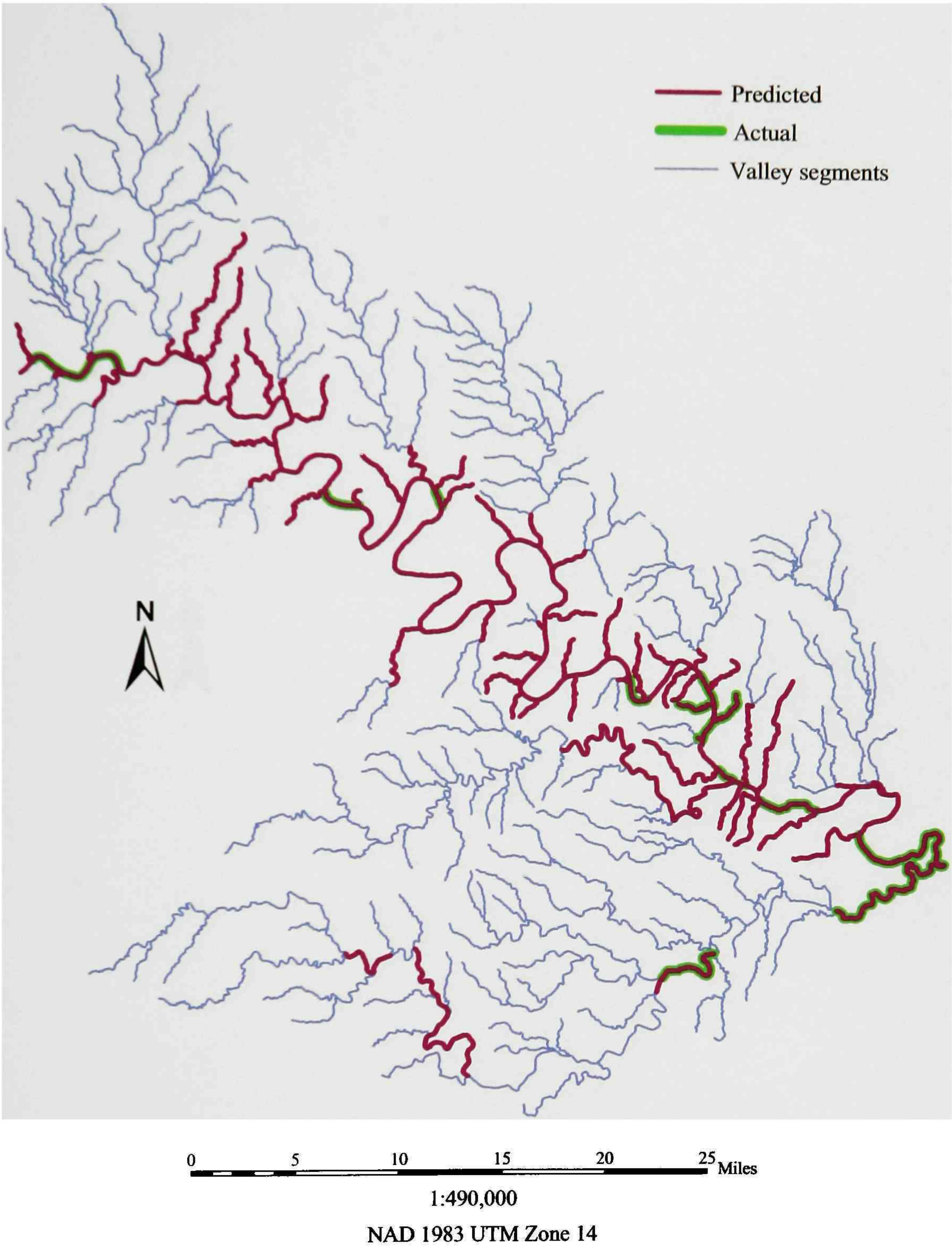

Figure 45. Species occurrence map: *Pimephales vigilax* in the Hydrologic Unit 12090205 of Central Texas

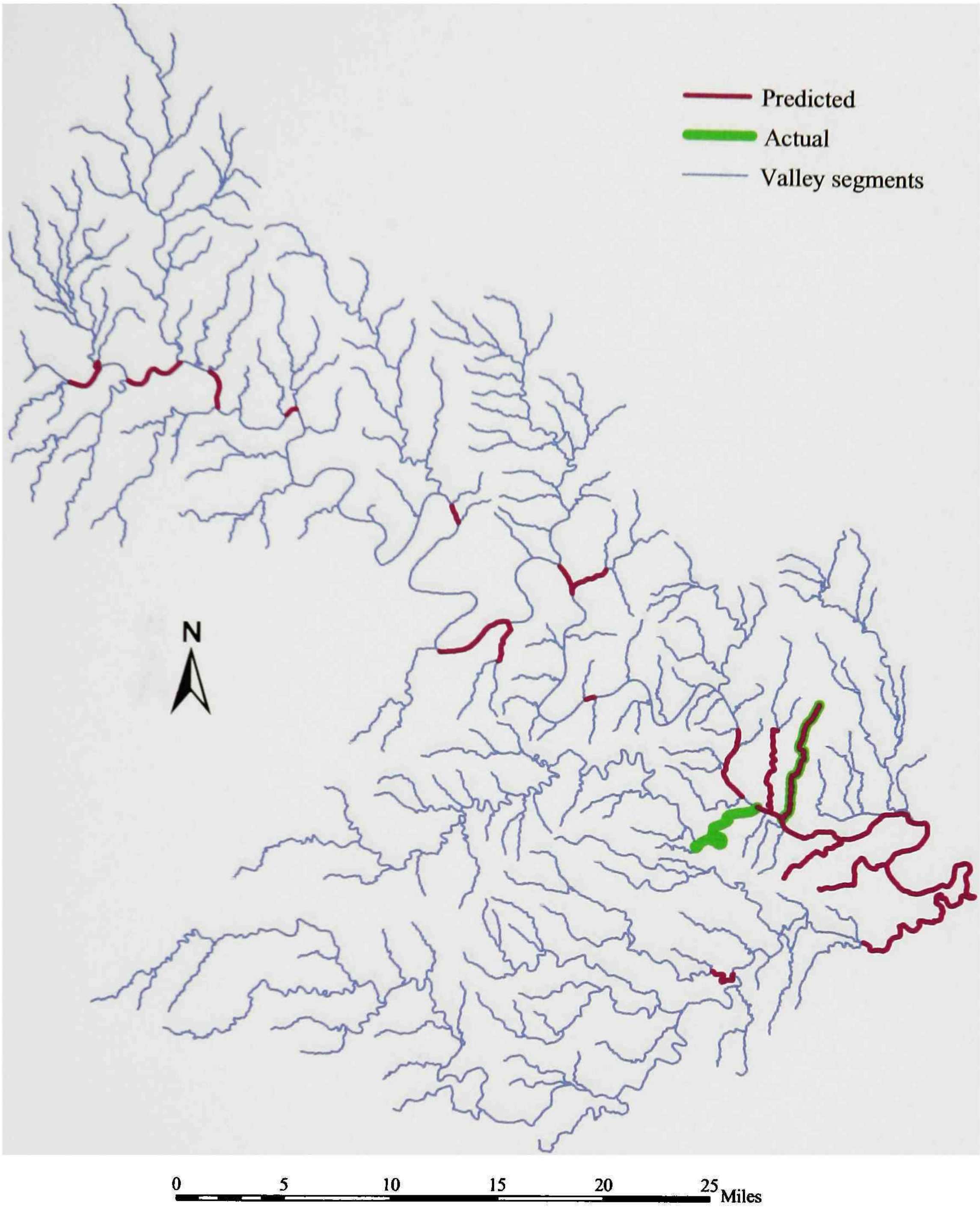

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Figure 46. Species occurrence map: *Carassius auratus* in the Hydrologic Unit 12090205 of Central Texas

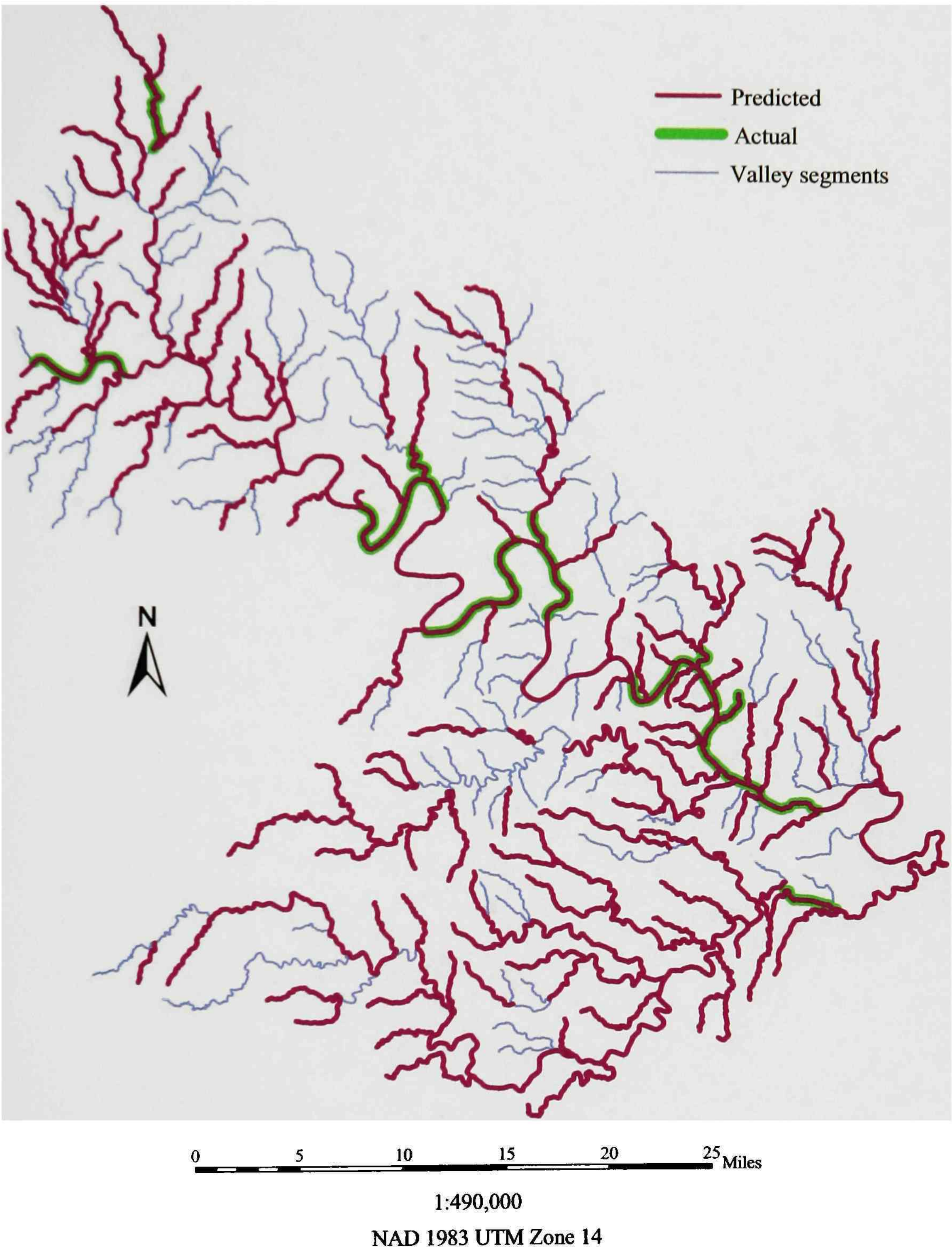

Figure 47. Species occurrence map: *Cyprinus carpio* in the Hydrologic Unit 12090205 of Central Texas

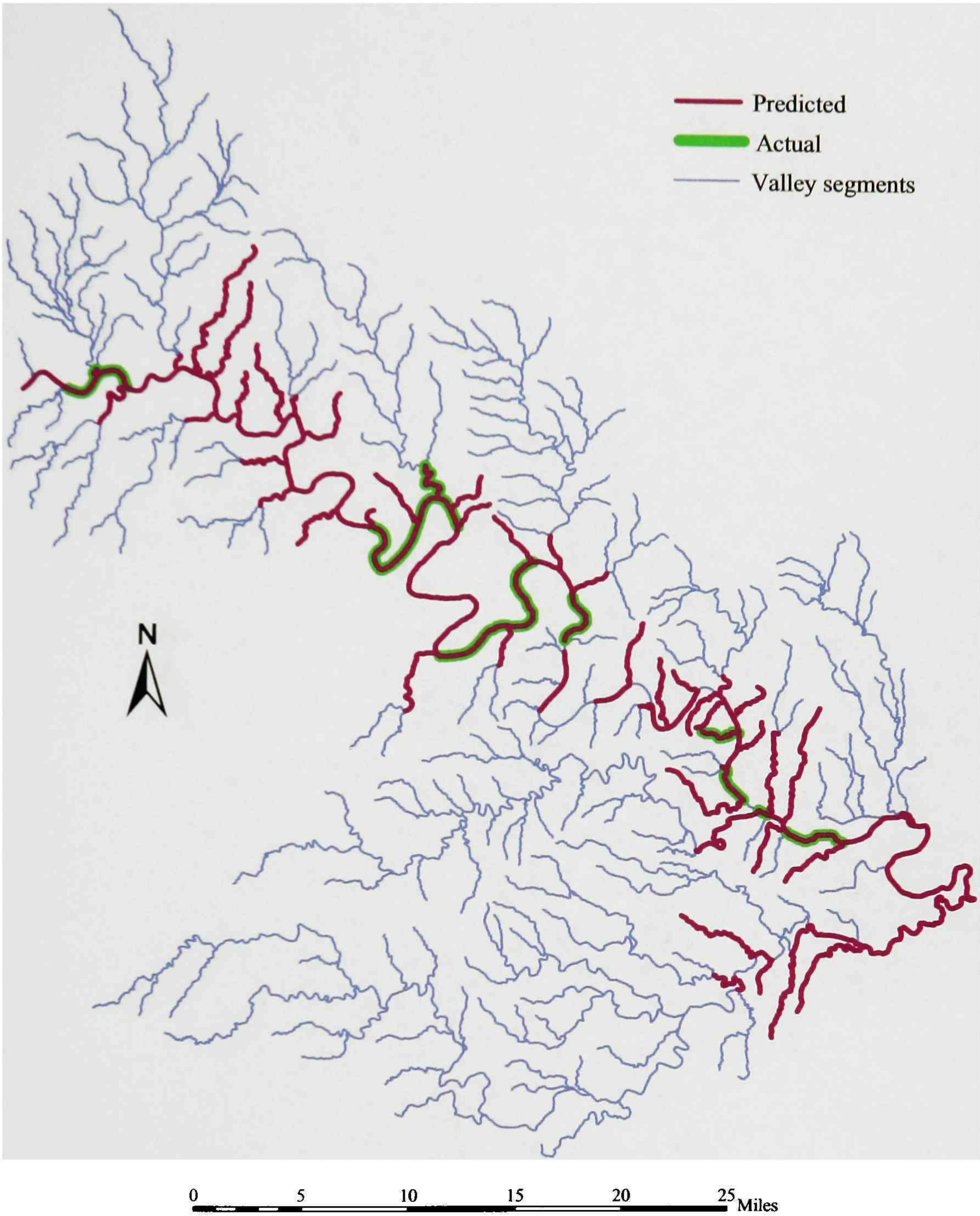

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Figure 48. Species occurrence map: *Carpiodes carpio* in the Hydrologic Unit 12090205 of Central Texas

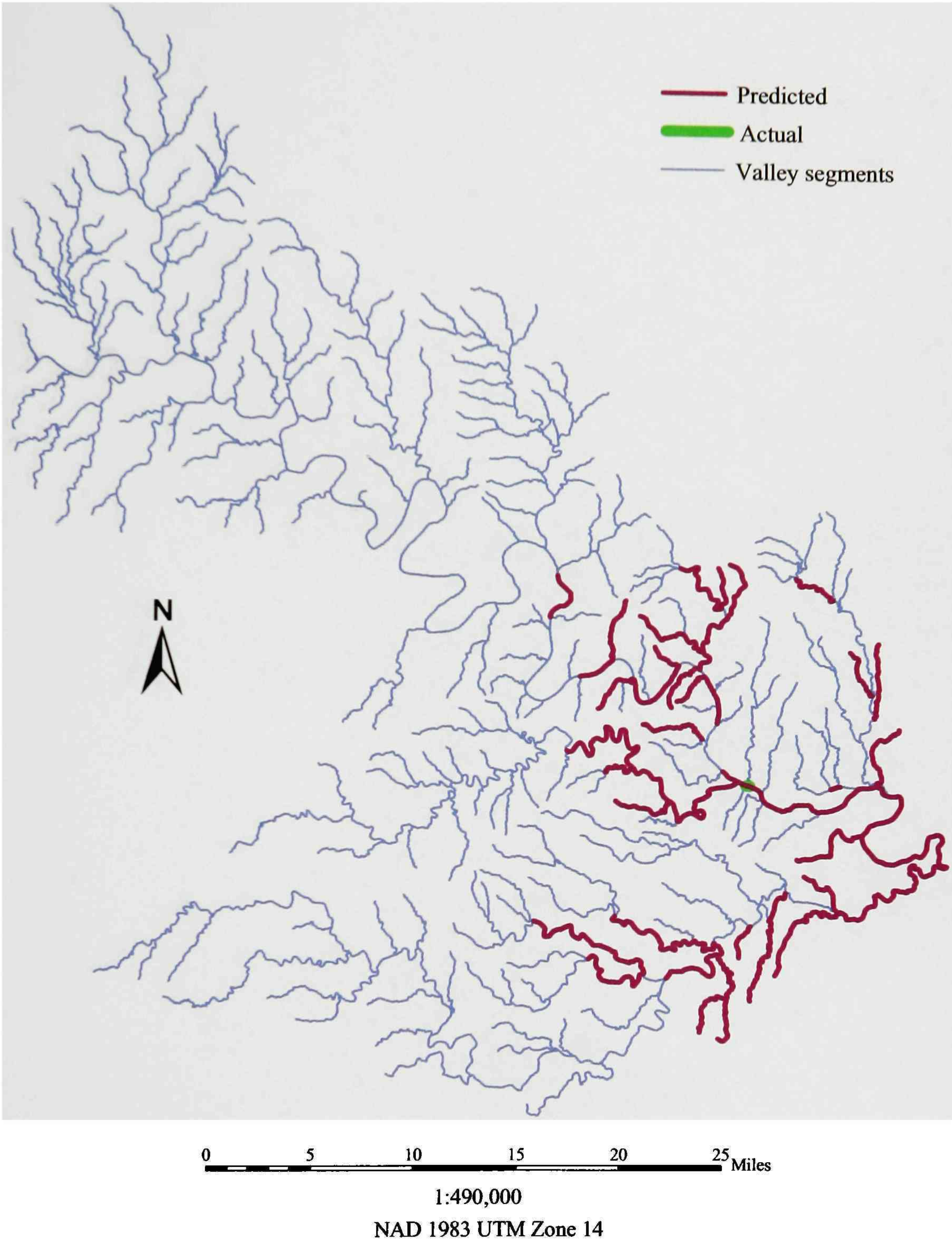


Figure 49. Species occurrence map: *Erimyzon sucetta* in the Hydrologic Unit 12090205 of Central Texas

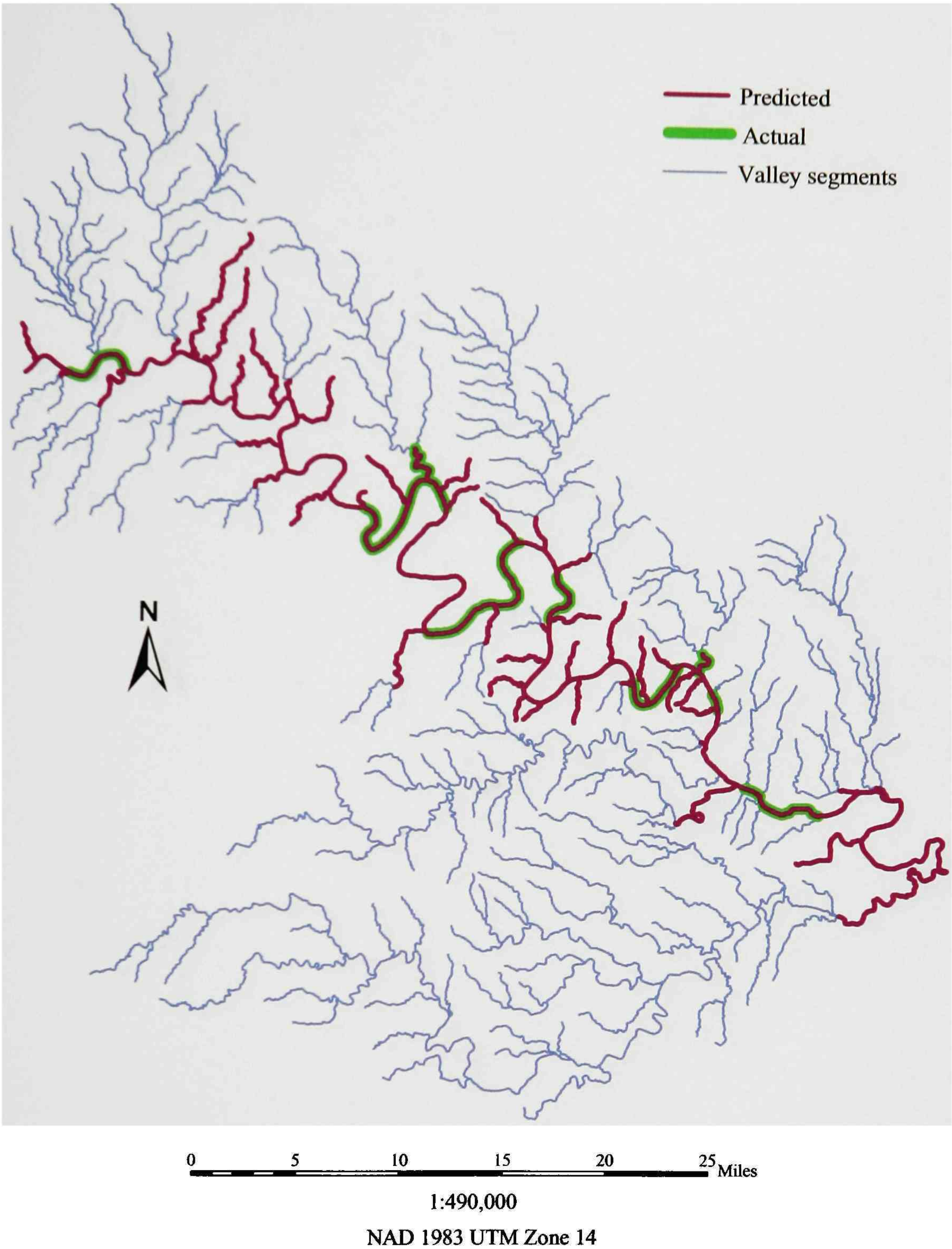


Figure 50. Species occurrence map: *Ictiobus bubalus* in the Hydrologic Unit 12090205 of Central Texas

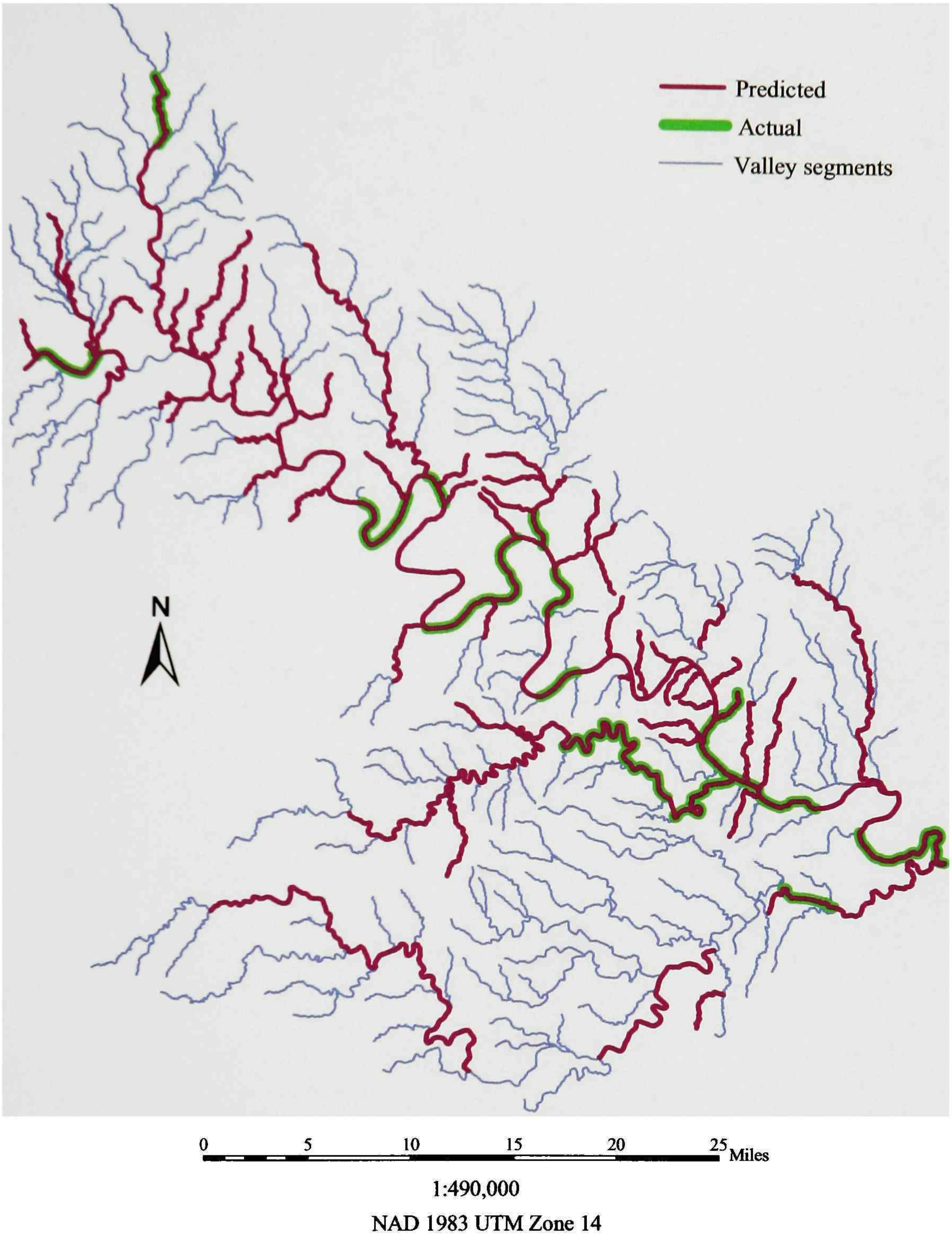


Figure 51. Species occurrence map: *Scartomyzon congestus* in the Hydrologic Unit 12090205 of Central Texas

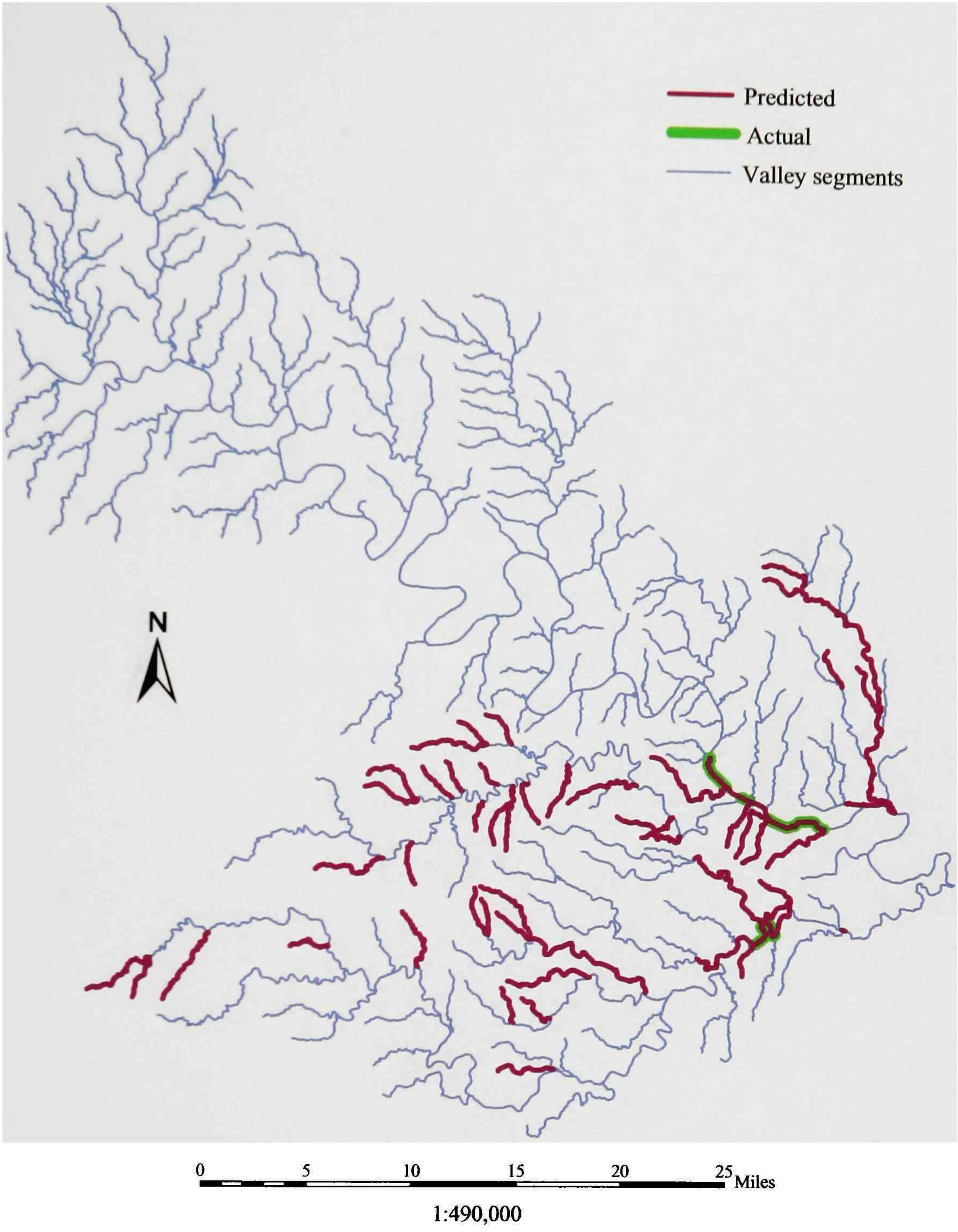


Figure 52. Species occurrence map: *Astyanax fasciatus* in the Hydrologic Unit 12090205 of Central Texas

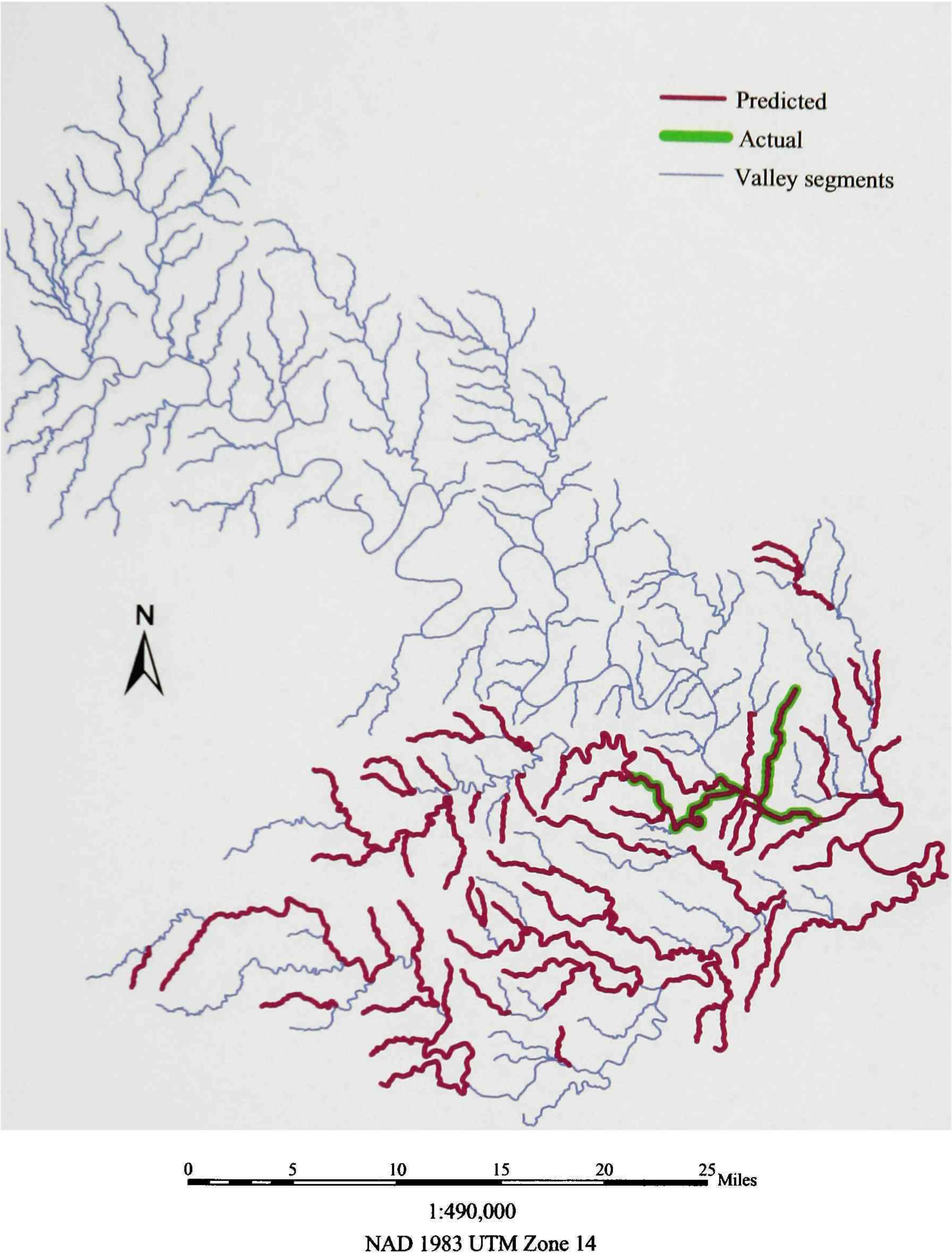


Figure 53. Species occurrence map: *Astyanax mexicanus* in the Hydrologic Unit 12090205 of Central Texas

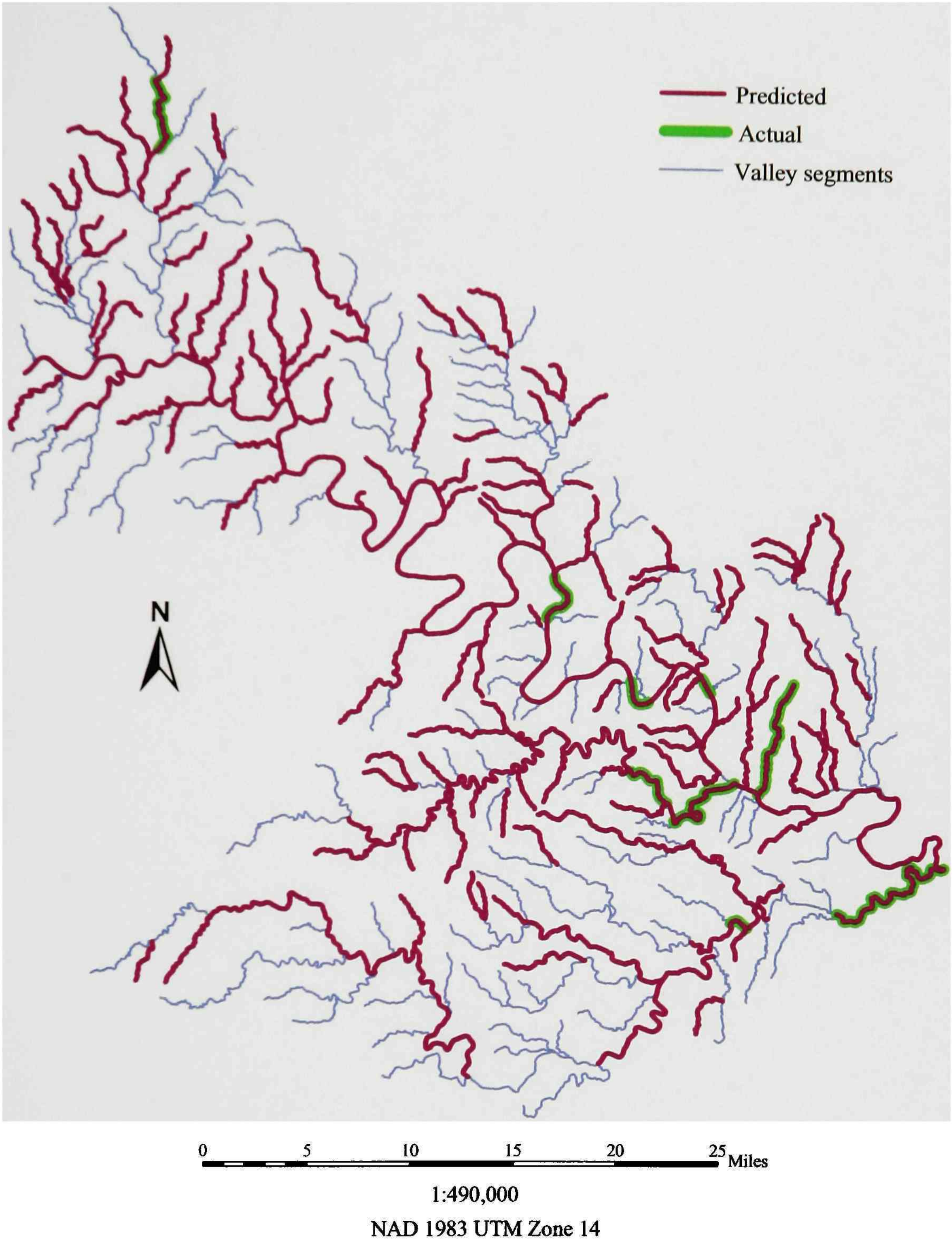


Figure 54. Species occurrence map: *Ameiurus melas* in the Hydrologic Unit 12090205 of Central Texas

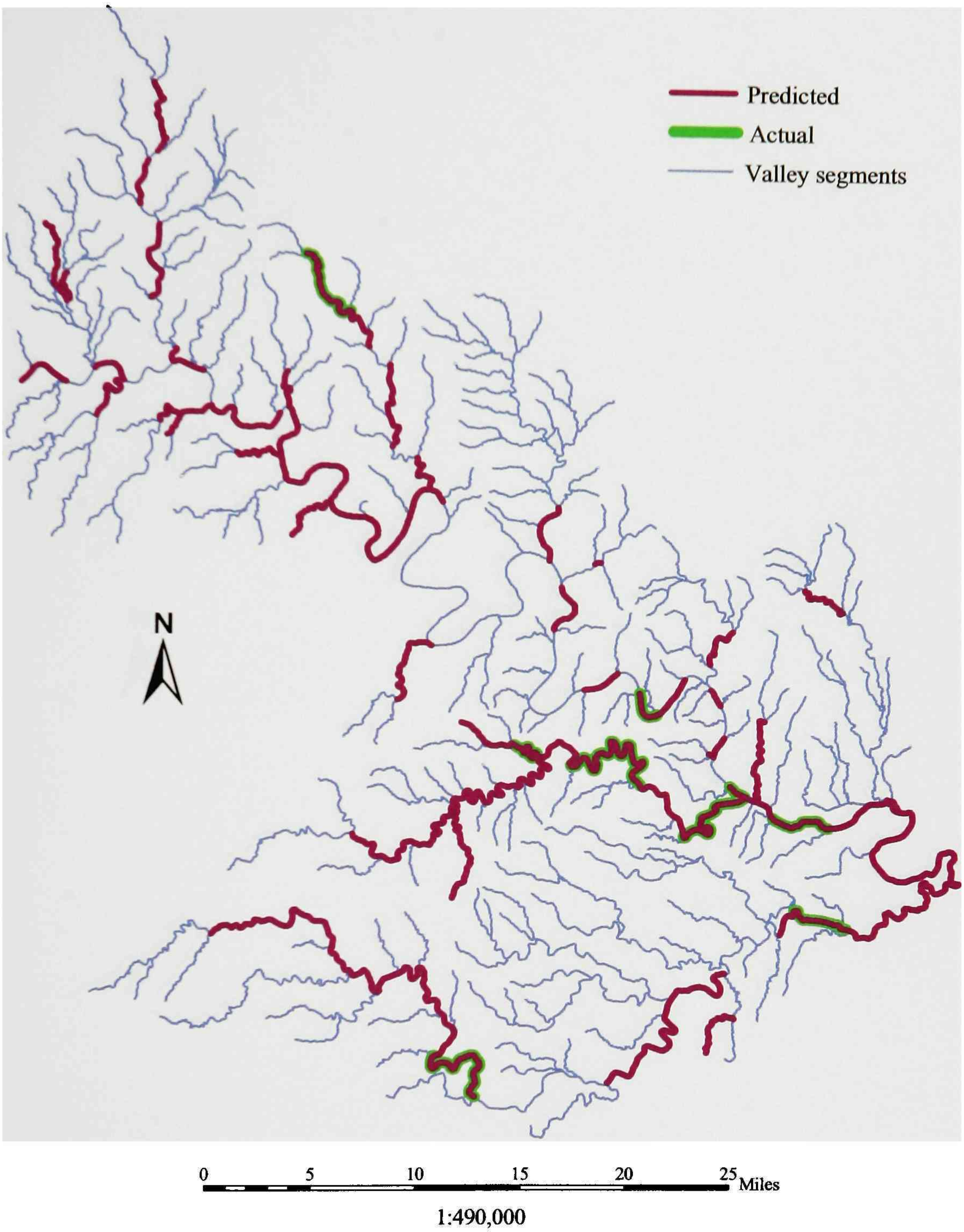


Figure 55. Species occurrence map: *Ameiurus natalis* in the Hydrologic Unit 12090205 of Central Texas

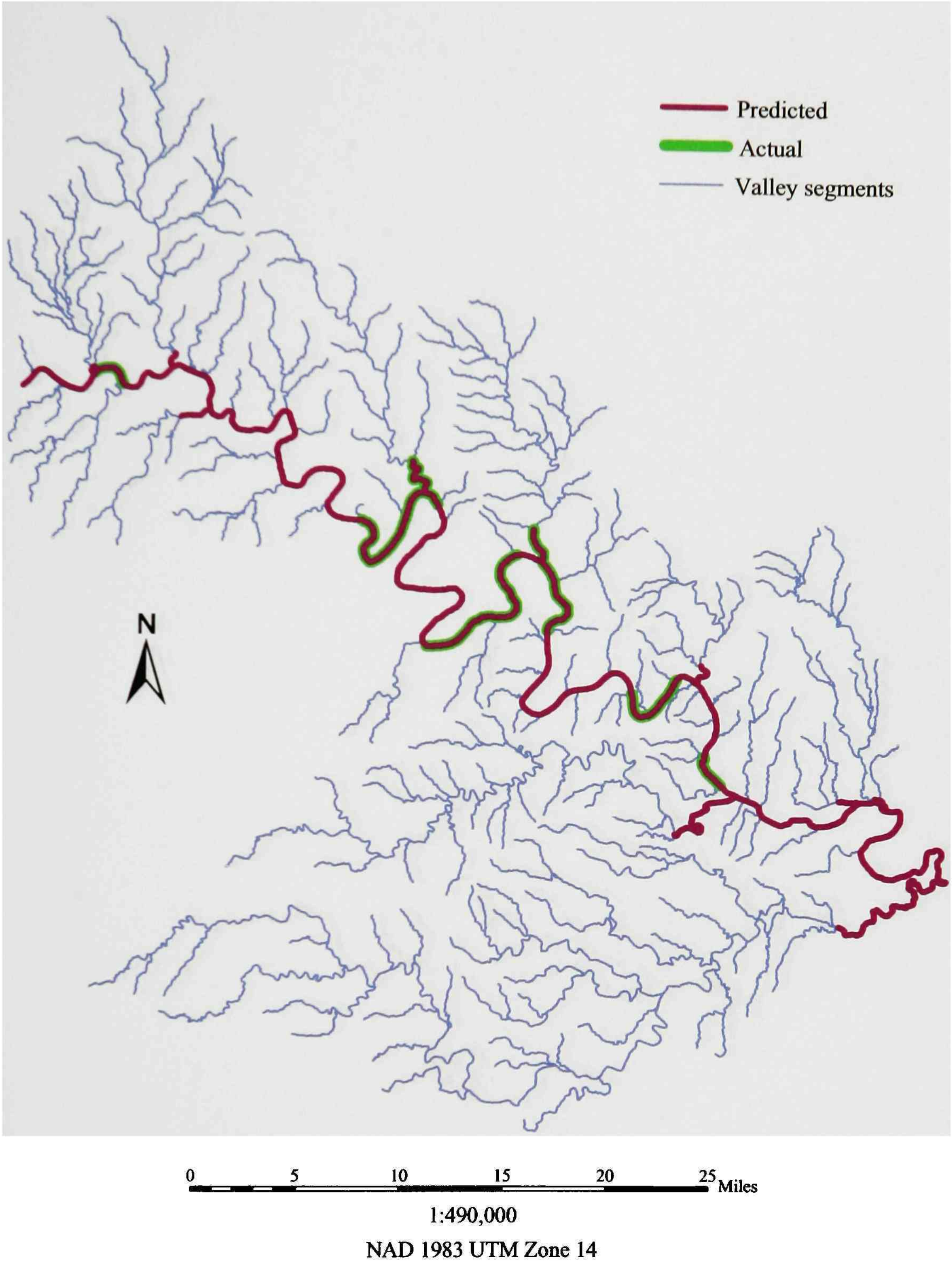
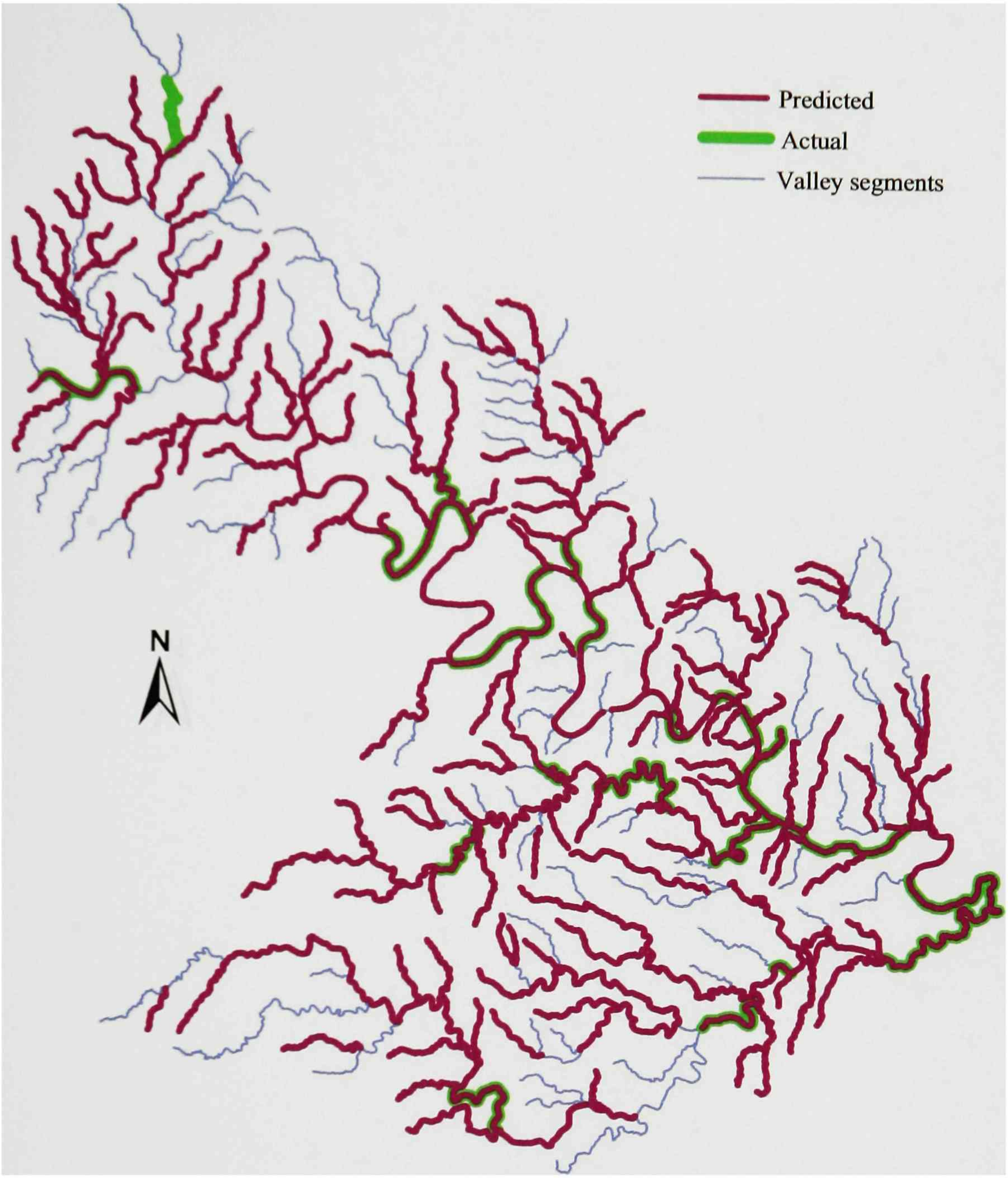


Figure 56. Species occurrence map: *Ictalurus furcatus* in the Hydrologic Unit 12090205 of Central Texas



0 5 10 15 20 25 Miles

1:490,000

NAD 1983 UTM Zone 14

Figure 57. Species occurrence map: *Ictalurus punctatus* in the Hydrologic Unit 12090205 of Central Texas

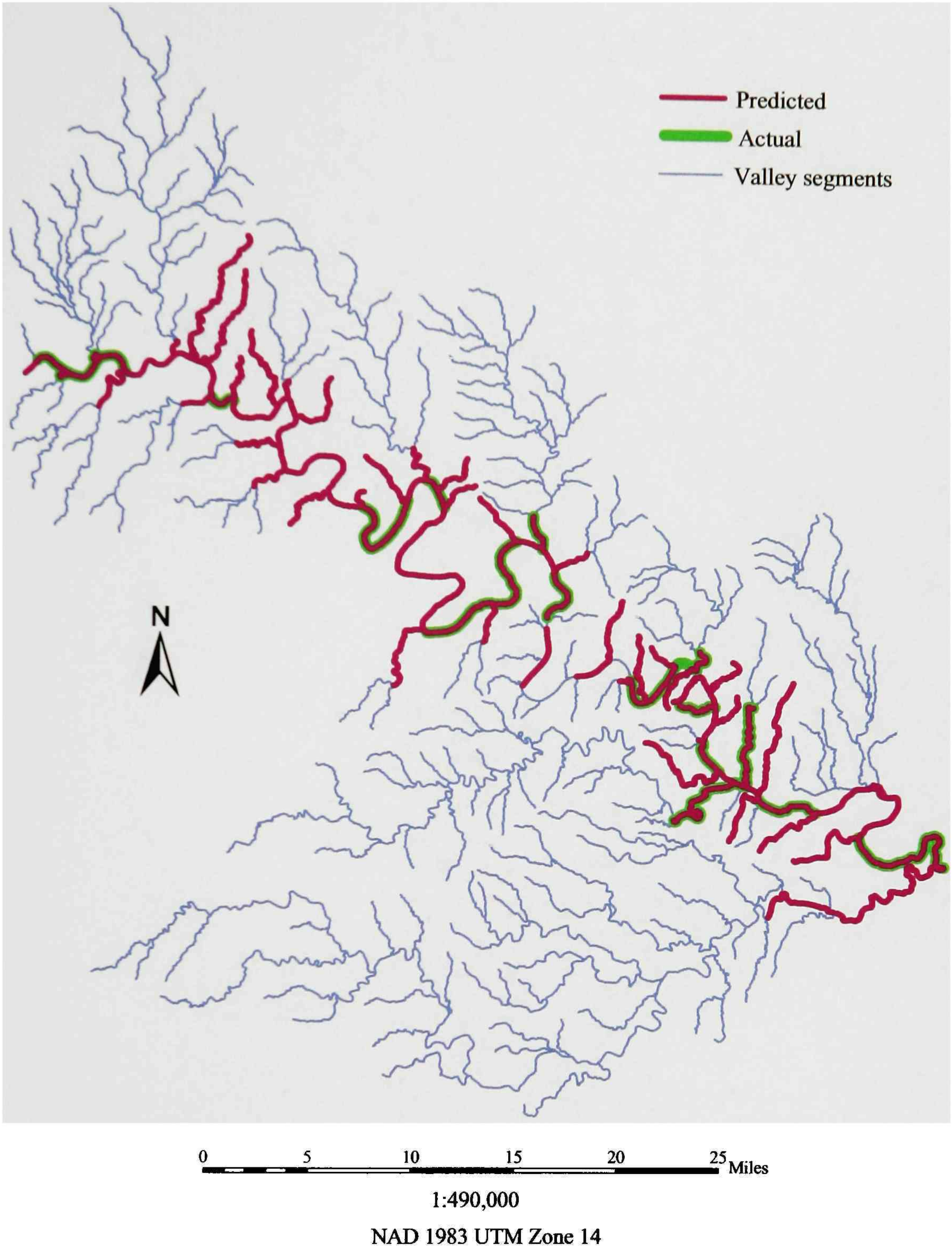


Figure 58. Species occurrence map: *Pylodictis olivaris* in the Hydrologic Unit 12090205 of Central Texas

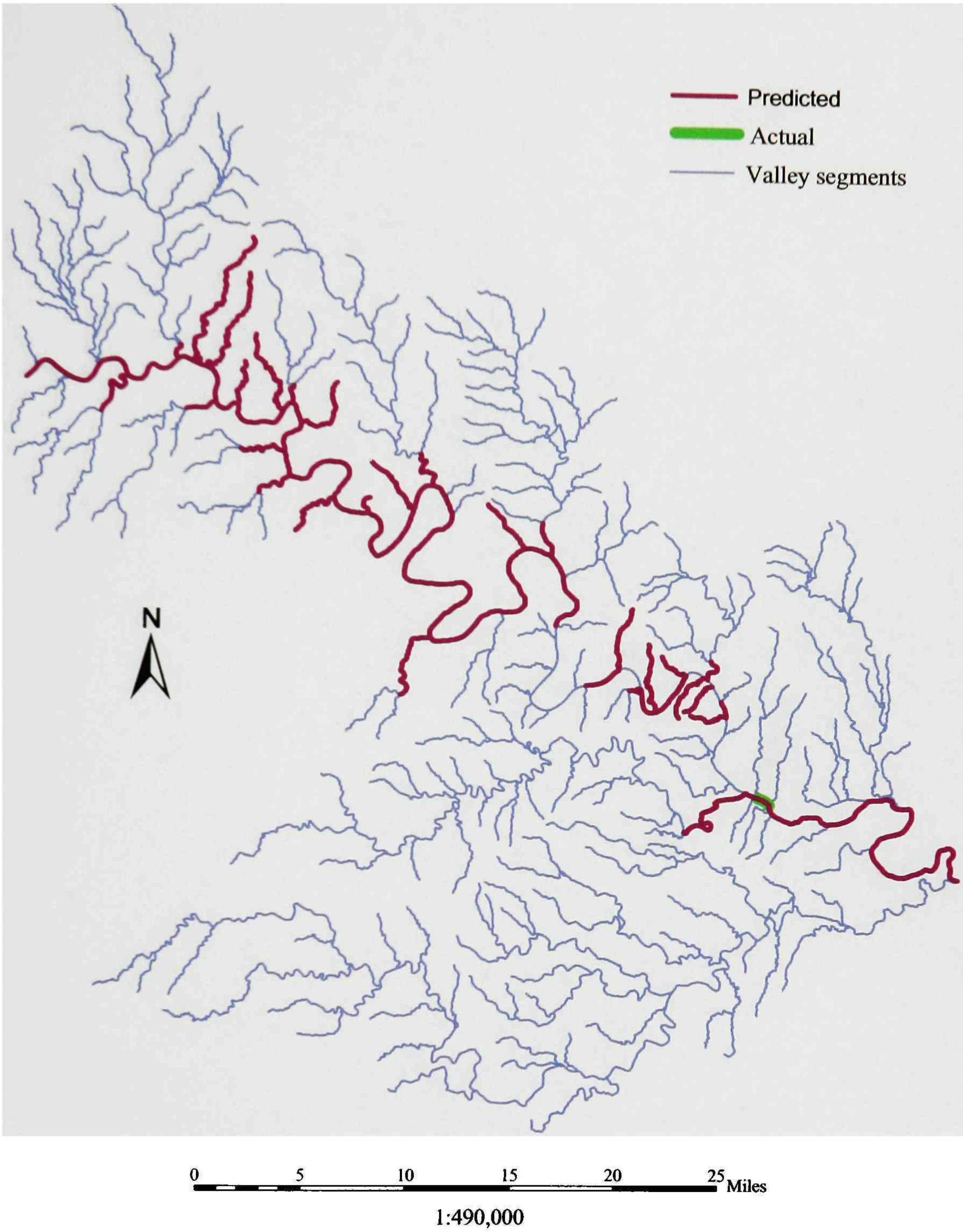


Figure 59. Species occurrence map: *Esox lucius* in the Hydrologic Unit 12090205 of Central Texas

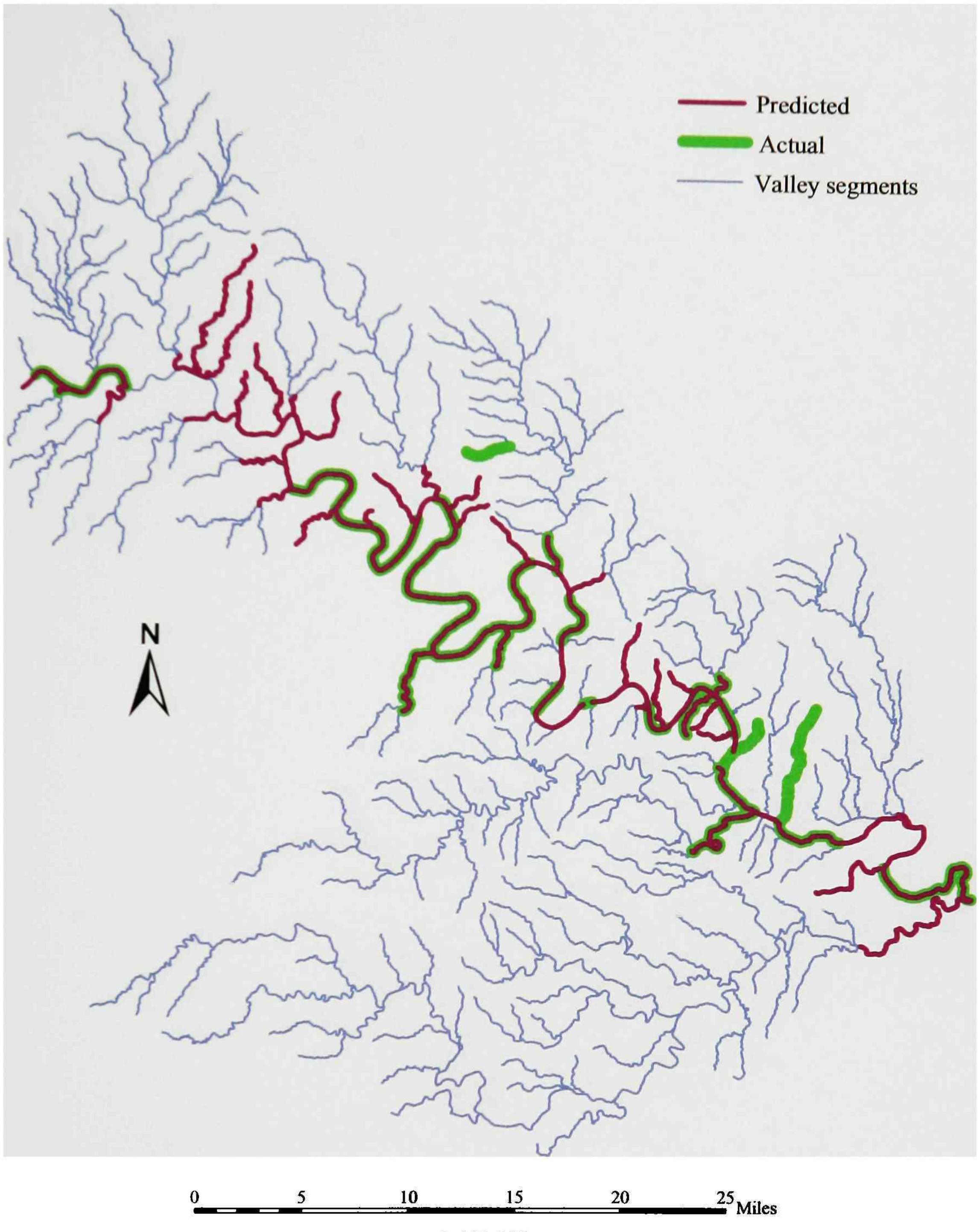


Figure 60. Species occurrence map: *Menidia beryllina* in the Hydrologic Unit 12090205 of Central Texas

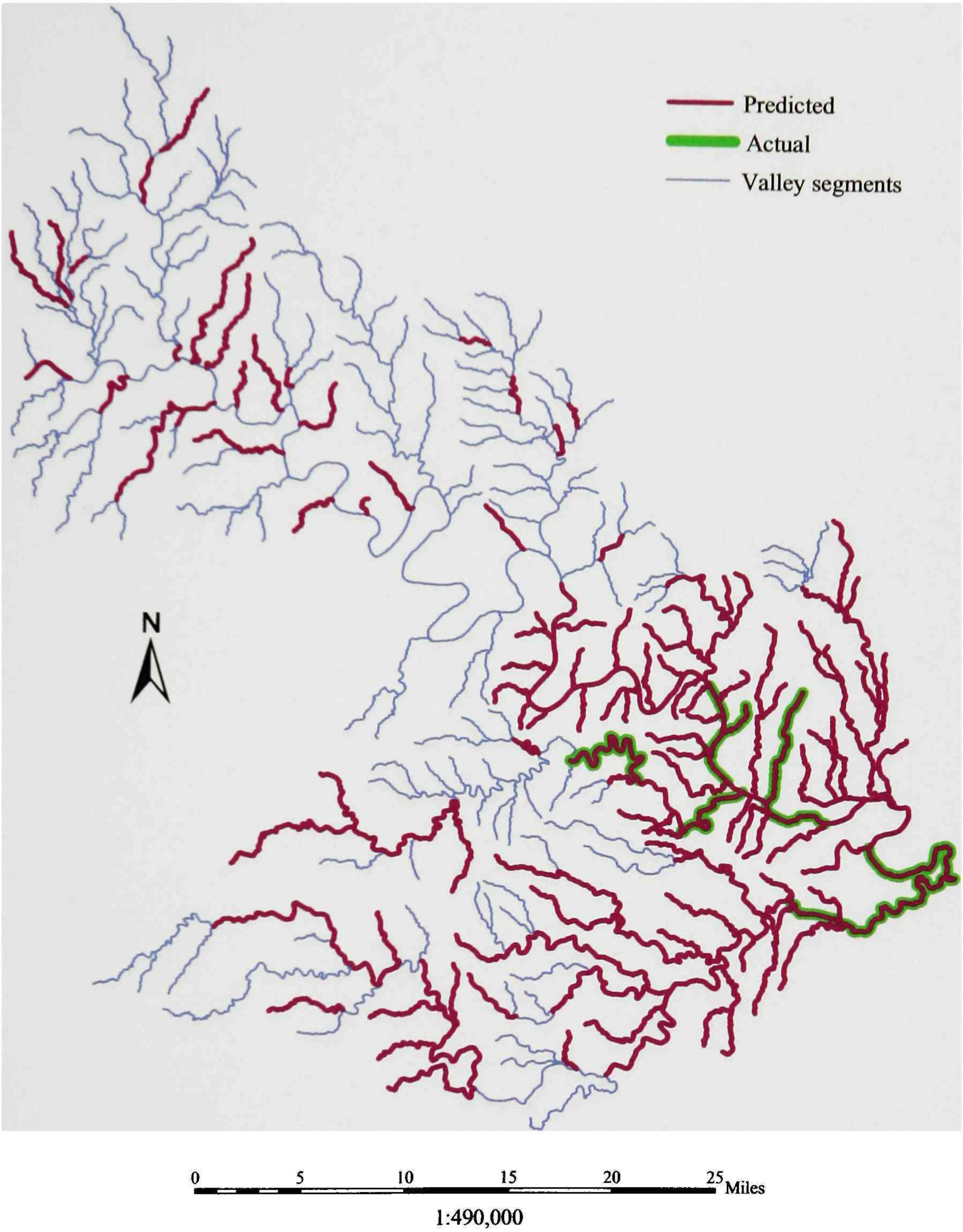


Figure 61. Species occurrence map: *Fundulus notatus* in the Hydrologic Unit 12090205 of Central Texas

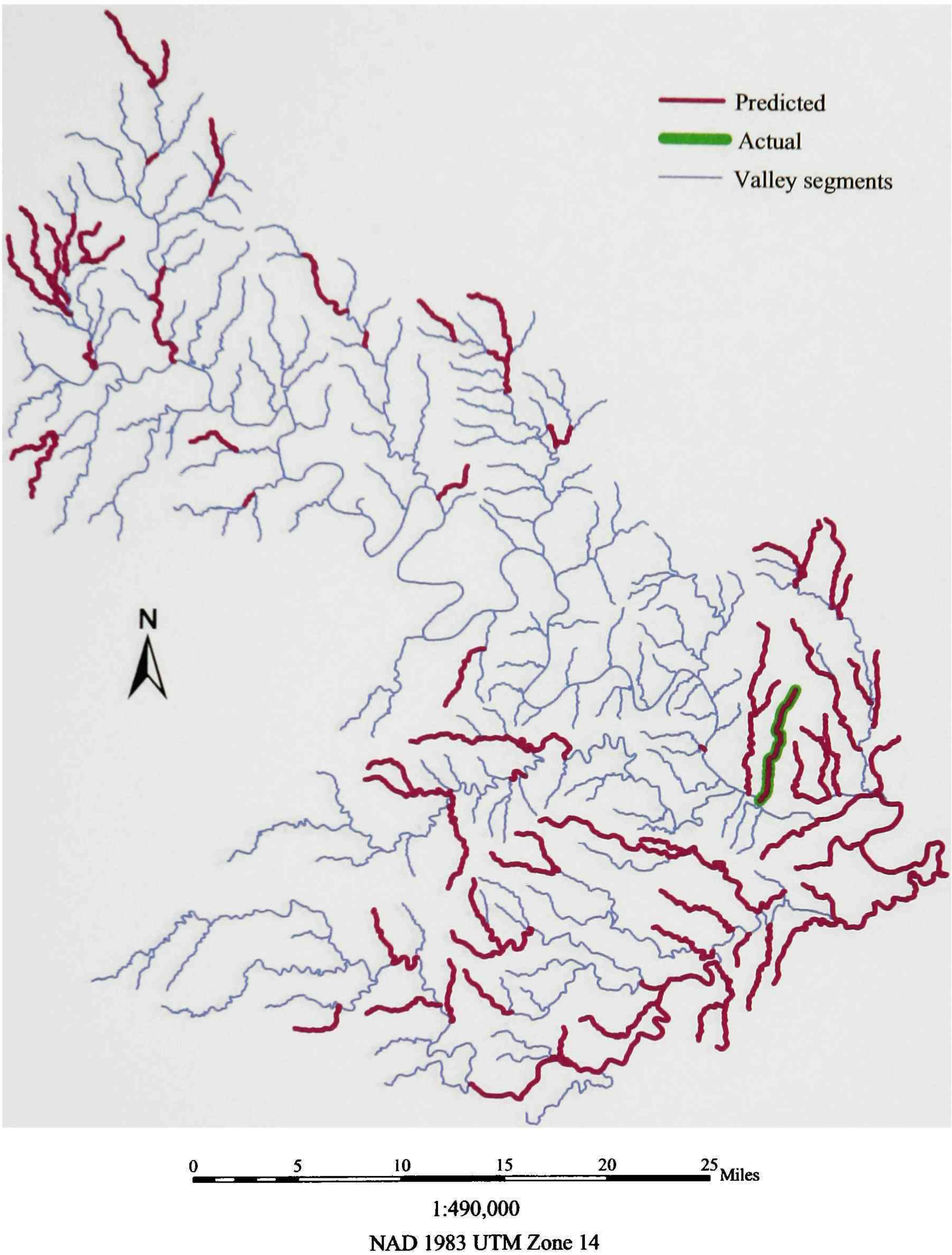


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Figure 62. Species occurrence map: *Fundulus zebrinus* in the Hydrologic Unit 12090205 of Central Texas

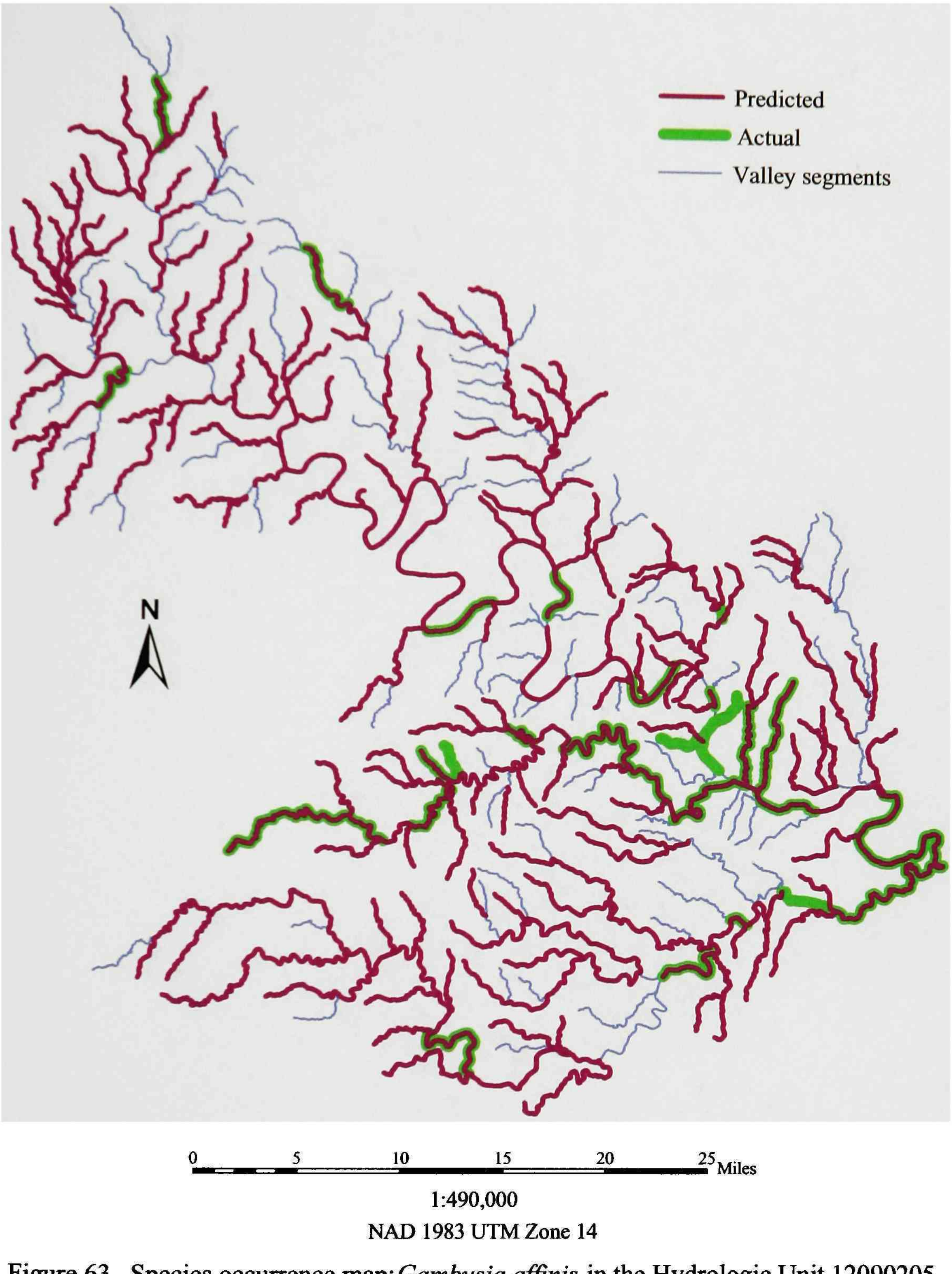

Figure 63. Species occurrence map: *Gambusia affinis* in the Hydrologic Unit 12090205 of central Texas

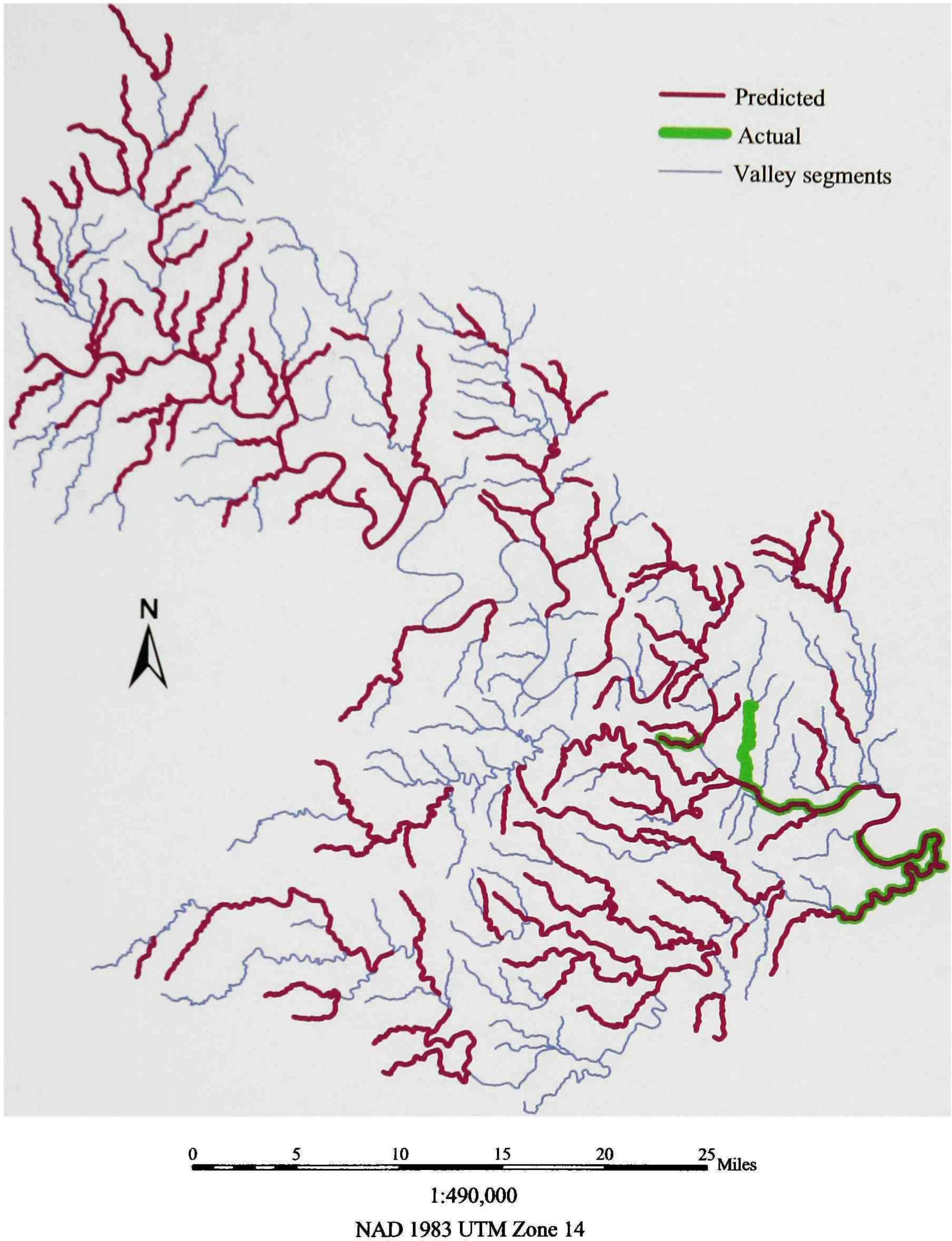

Figure 64. Species occurrence map: *Poecilia latipinna* in the Hydrologic Unit 12090205 of Central Texas

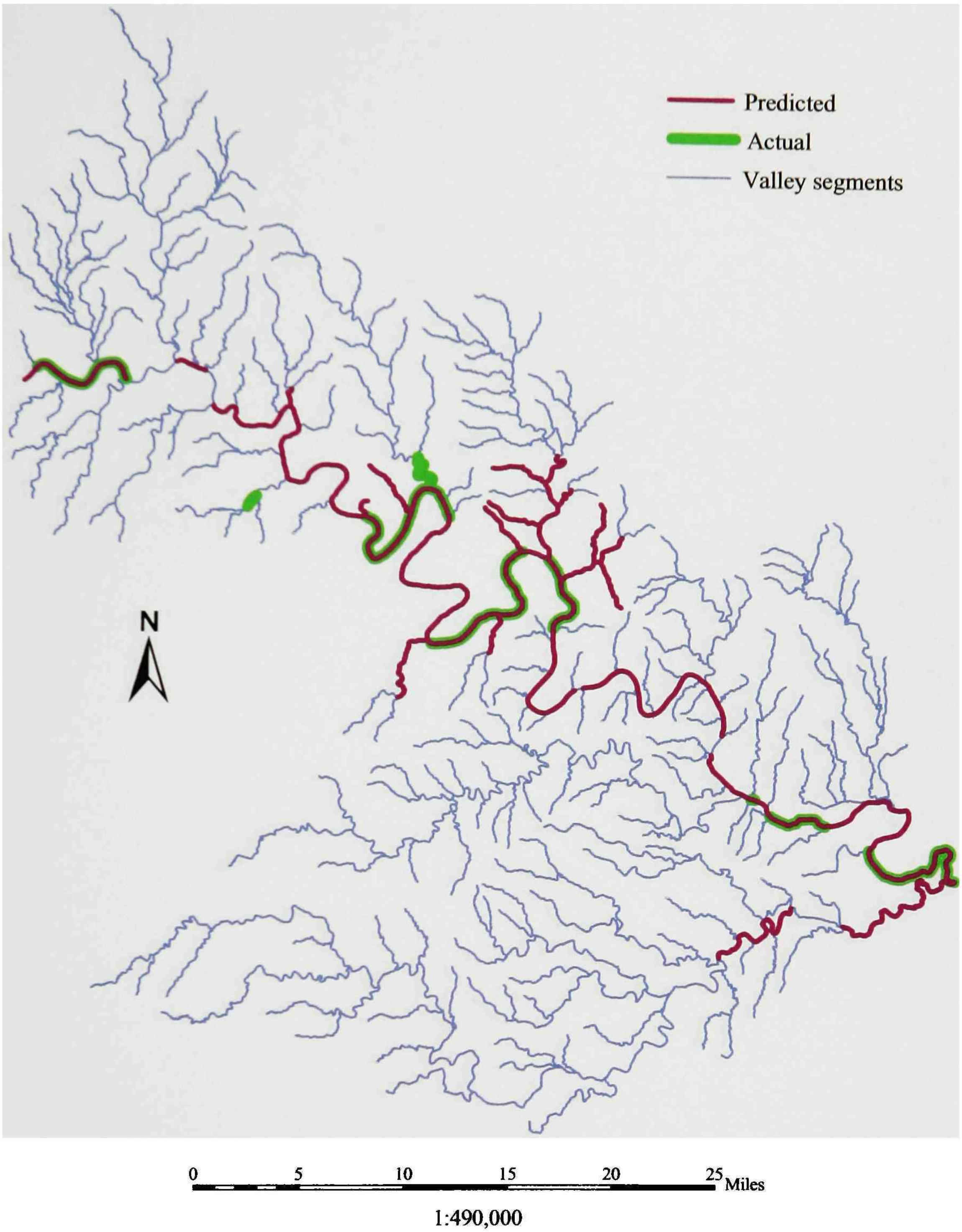

Figure 65. Species occurrence map: *Morone chrysops* in the Hydrologic Unit 12090205 of Central Texas

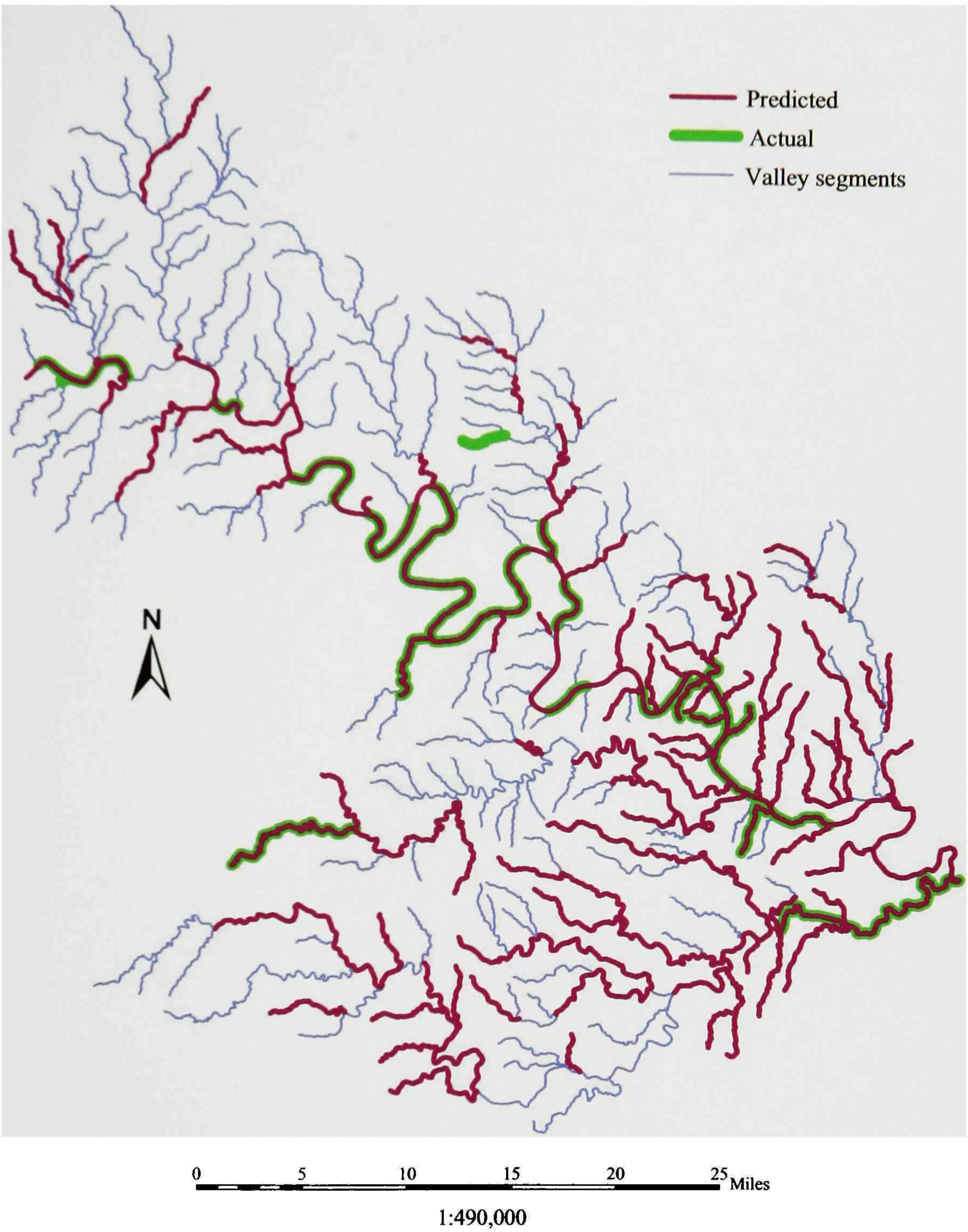

Figure 66. Species occurrence map: *Chaenobryttus gulosus* (*Lepomis gulosus*) in the Hydrologic Unit 12090205 of Central Texas

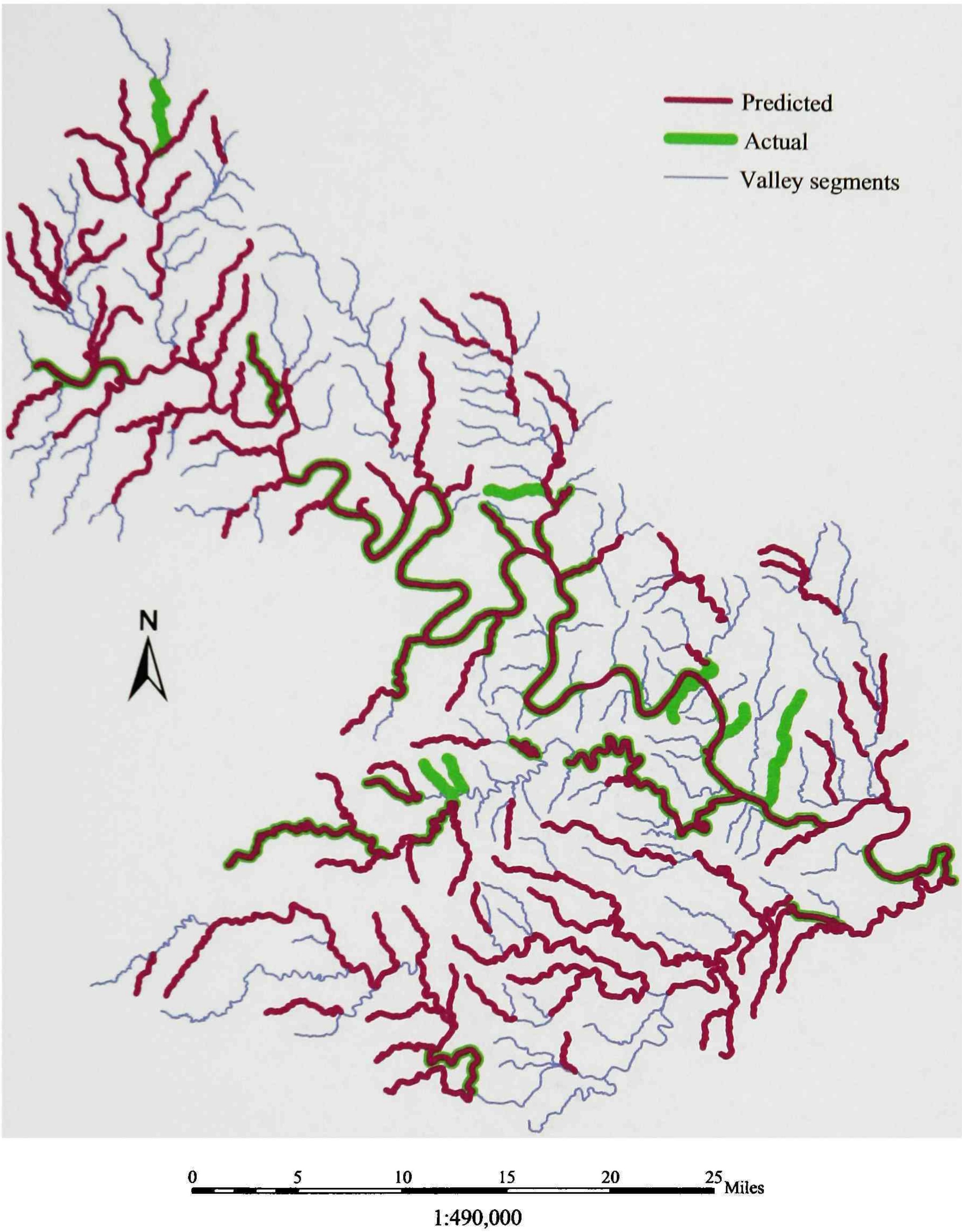

Figure 67. Species occurrence map: *Lepomis auritus* in the Hydrologic Unit 12090205 of Central Texas

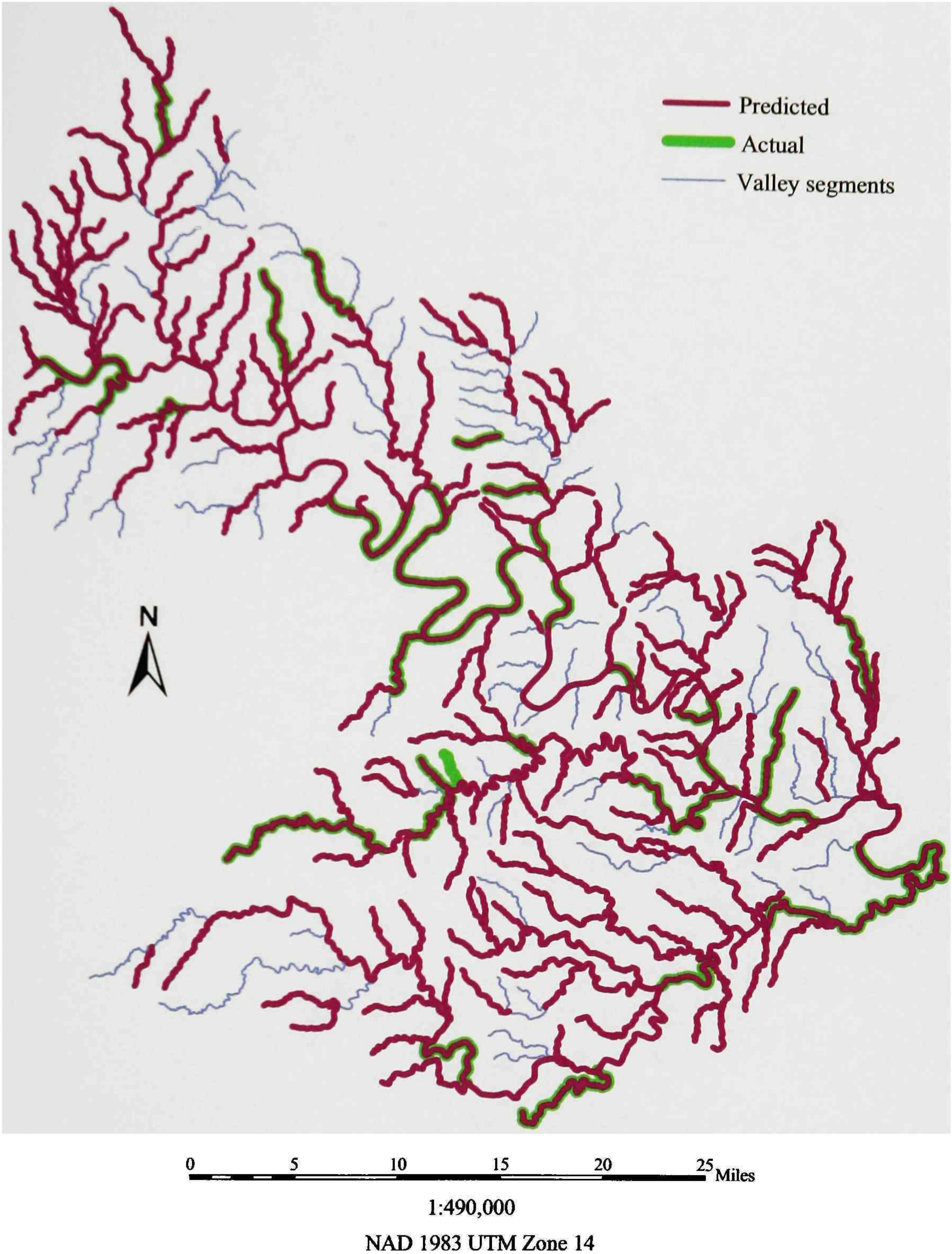

Figure 68. Species occurrence map: *Lepomis cyanellus* in the Hydrologic Unit 12090205 of Central Texas

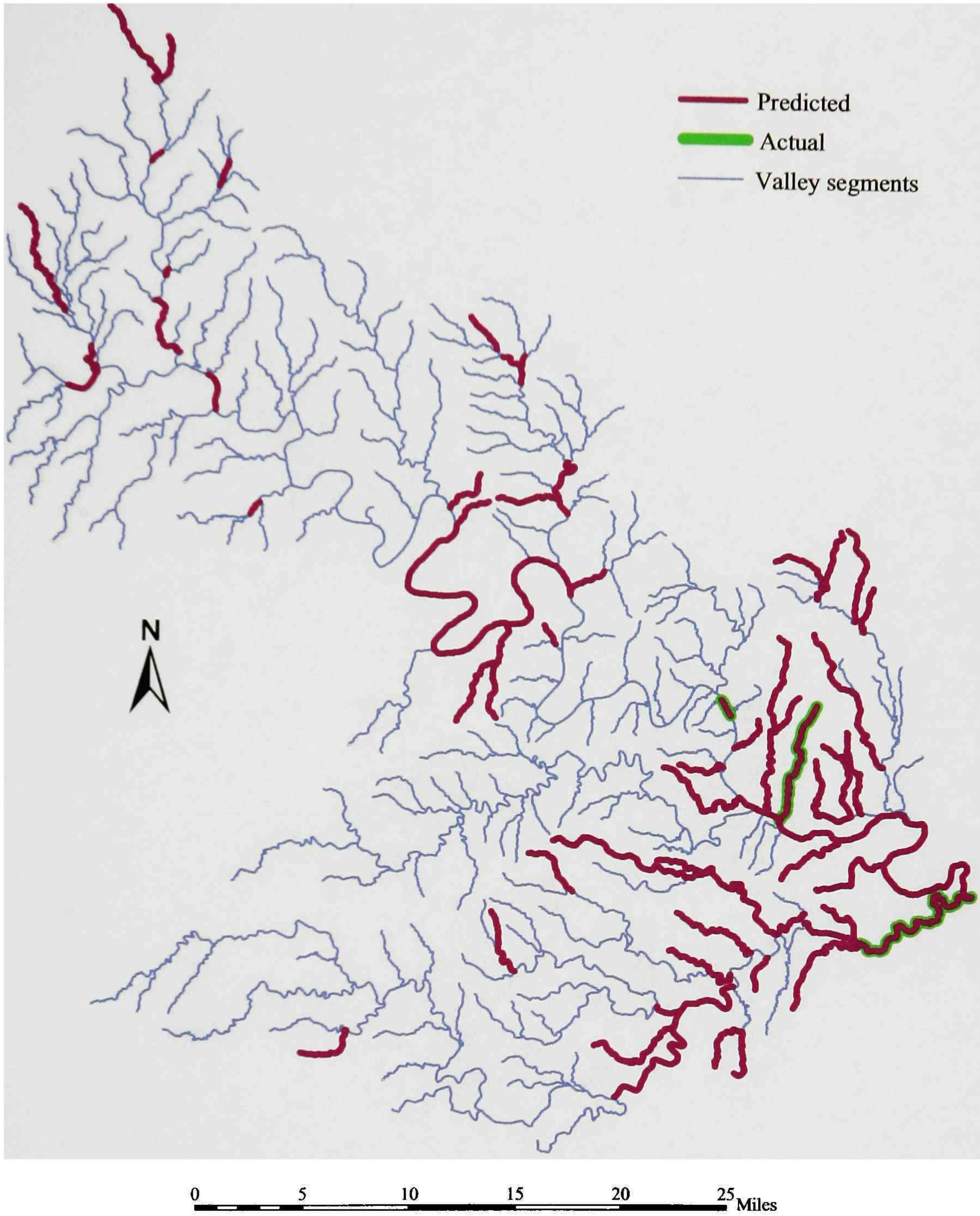

Figure 69. Species occurrence map: *Lepomis humilis* in the Hydrologic Unit 12090205 of Central Texas

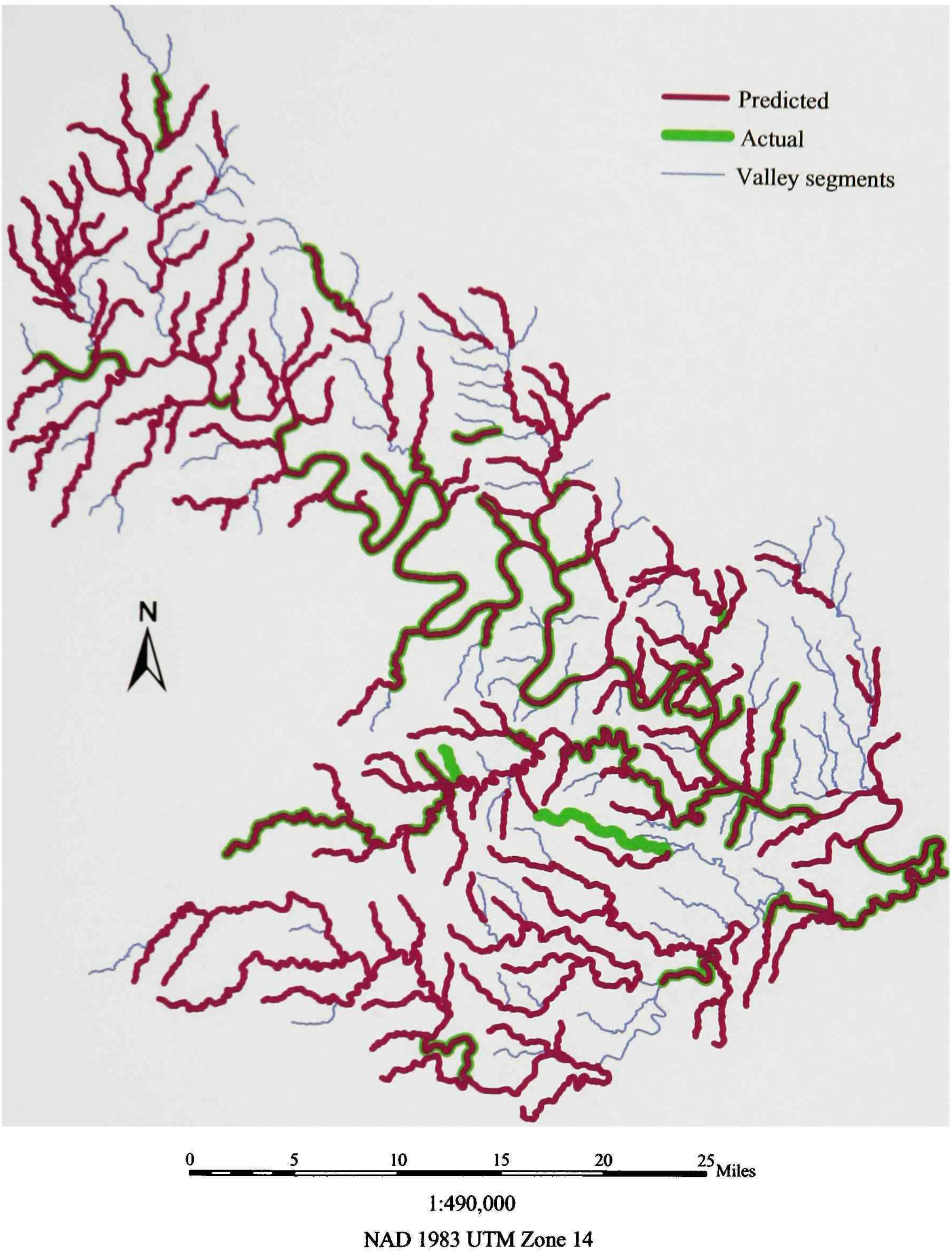

Figure 70. Species occurrence map: *Lepomis macrochirus* in the Hydrologic Unit 12090205 of Central Texas

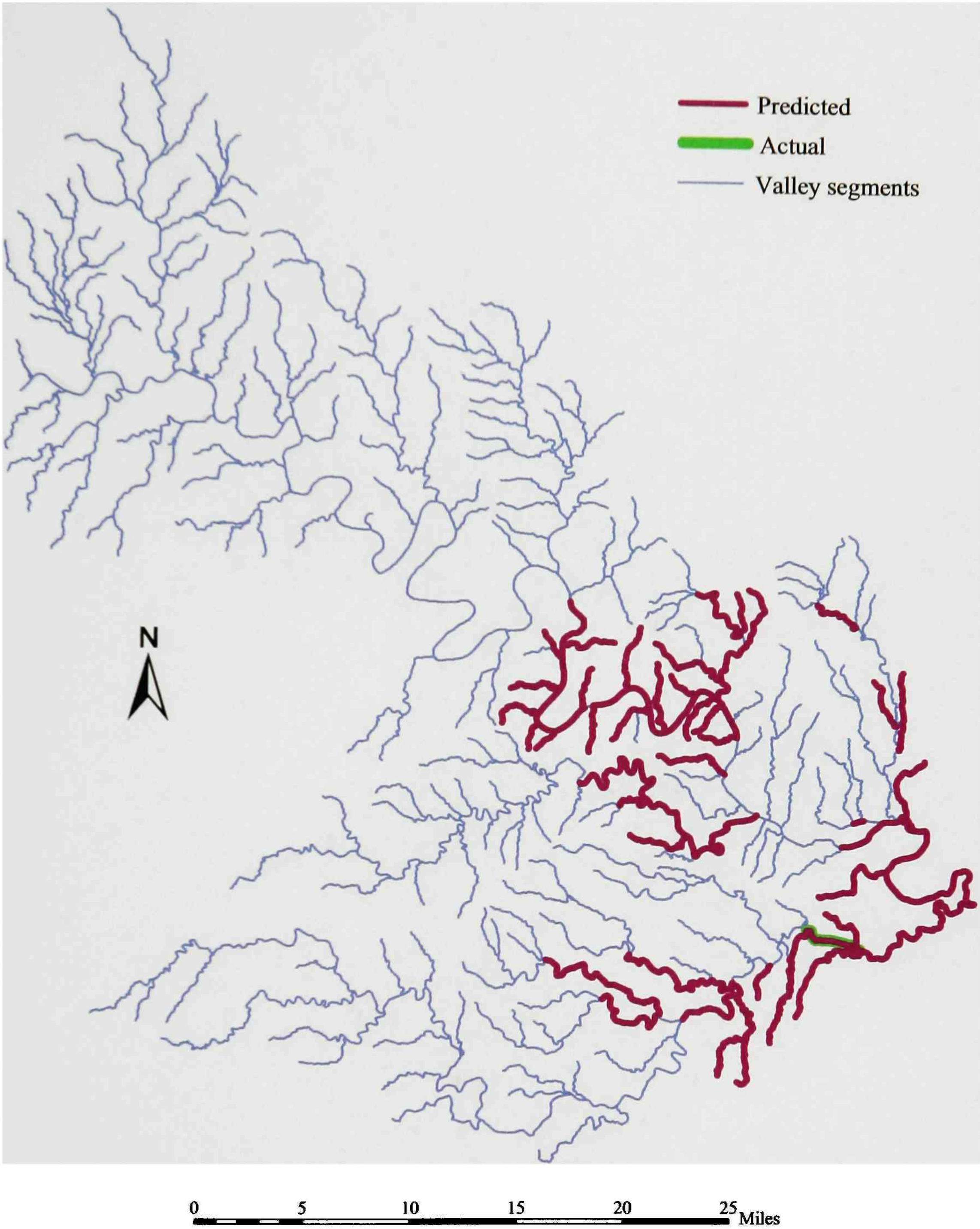

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Figure 71. Species occurrence map: *Lepomis marginatus* in the Hydrologic Unit 12090205 of Central Texas

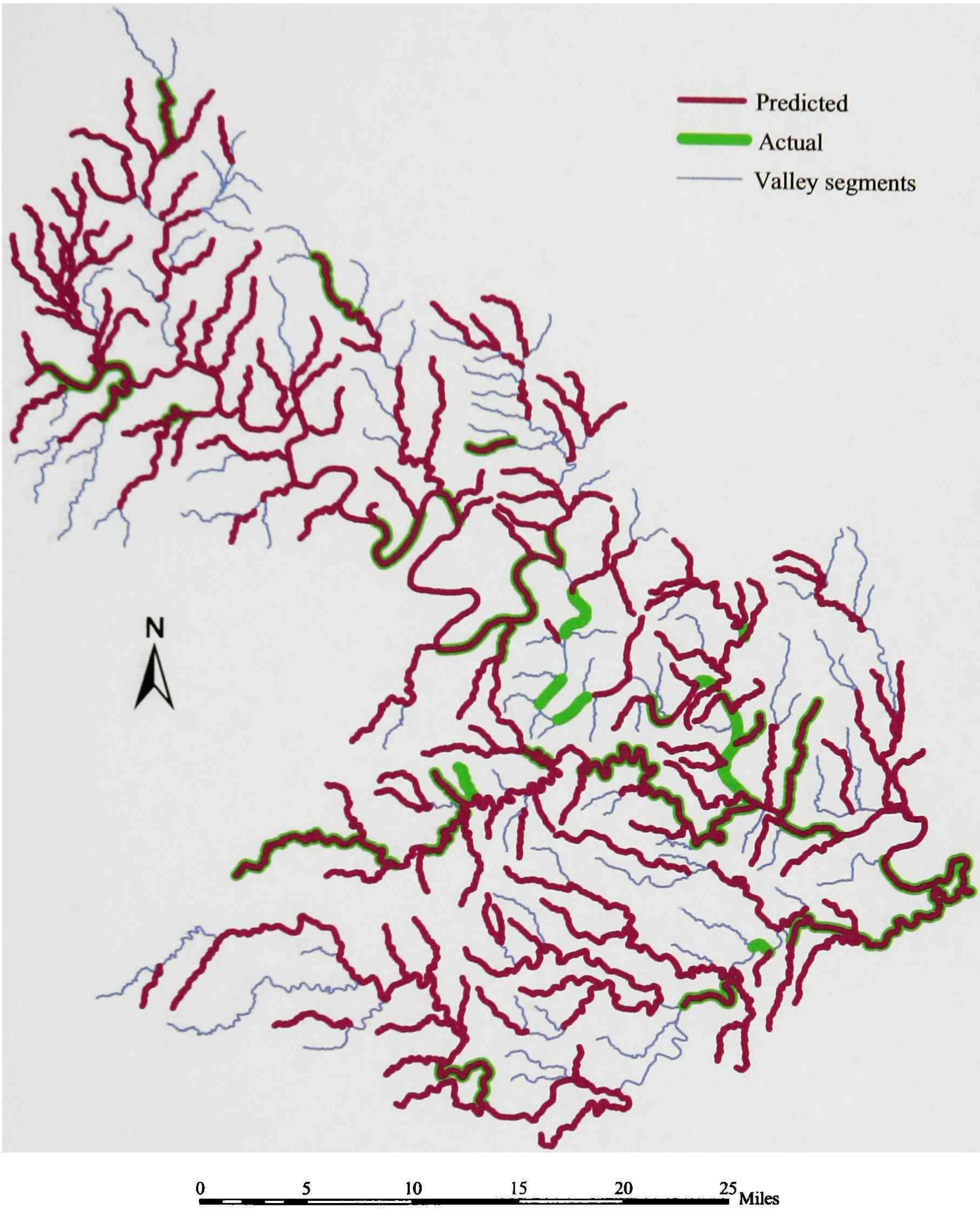

Figure 72. Species occurrence map: *Lepomis megalotis* in the Hydrologic Unit 12090205 of Central Texas

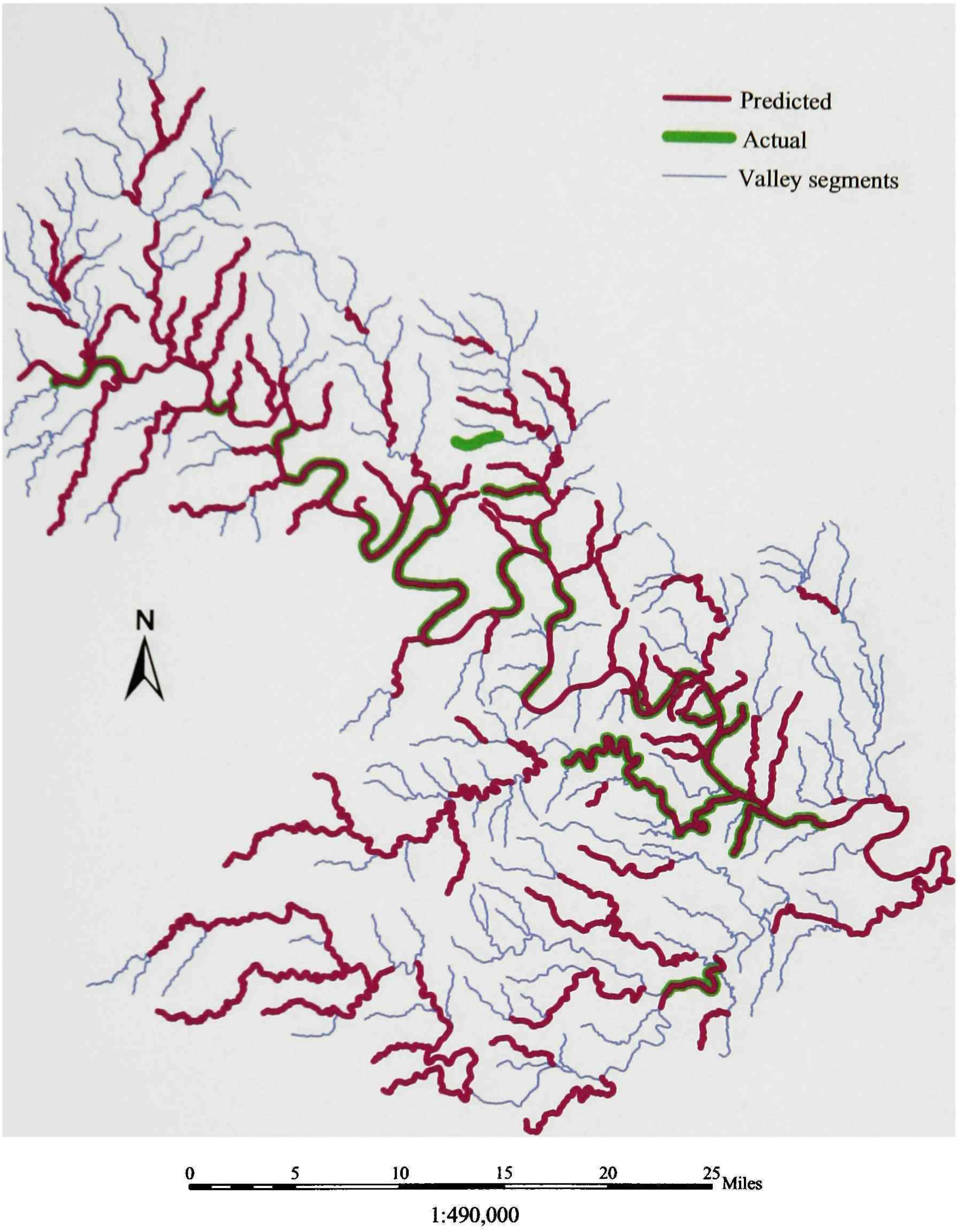

Figure 73. Species occurrence map: *Lepomis microlophus* in the Hydrologic Unit 12090205 of Central Texas

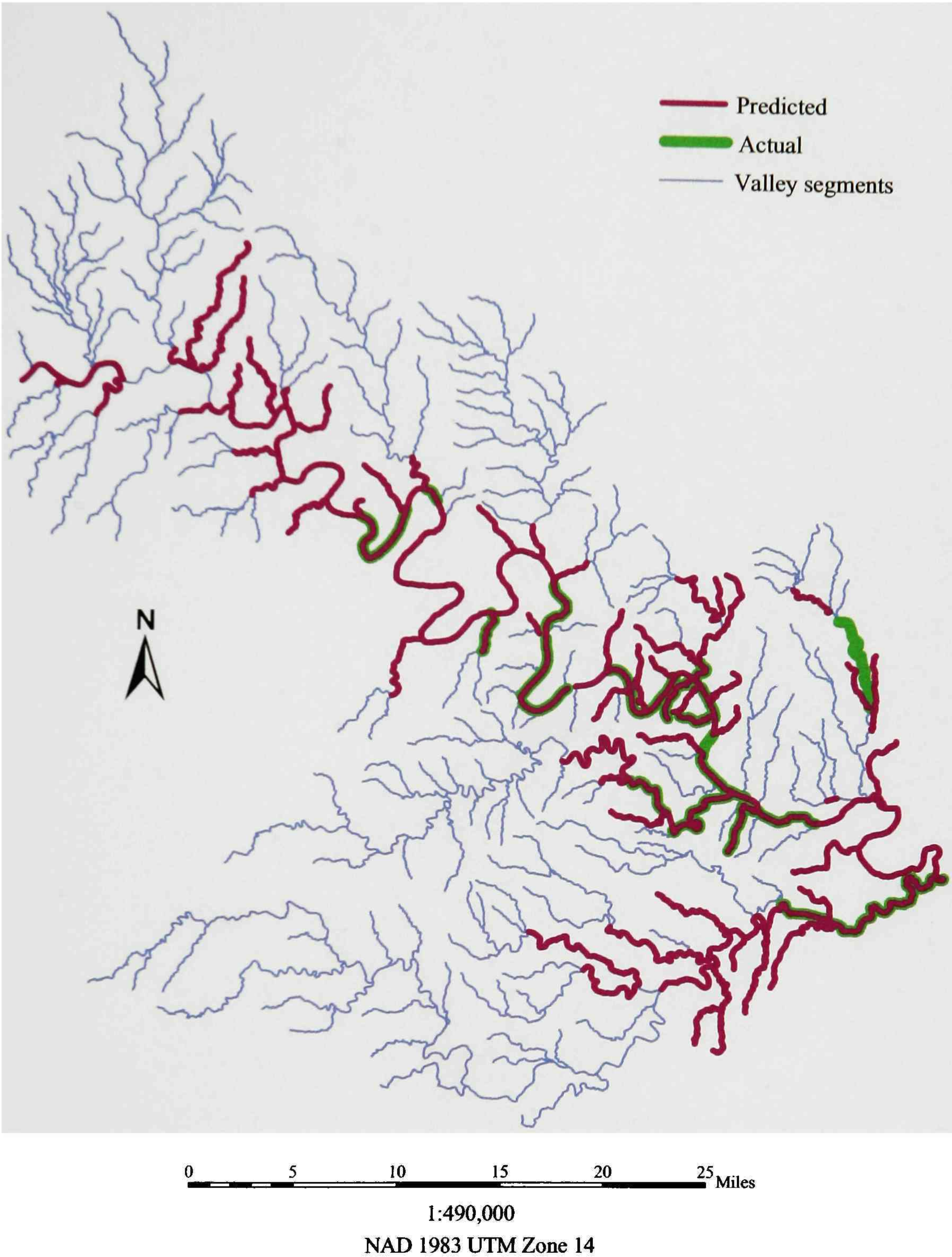

Figure 74. Species occurrence map: *Lepomis punctatus* in the Hydrologic Unit 12090205 of Central Texas

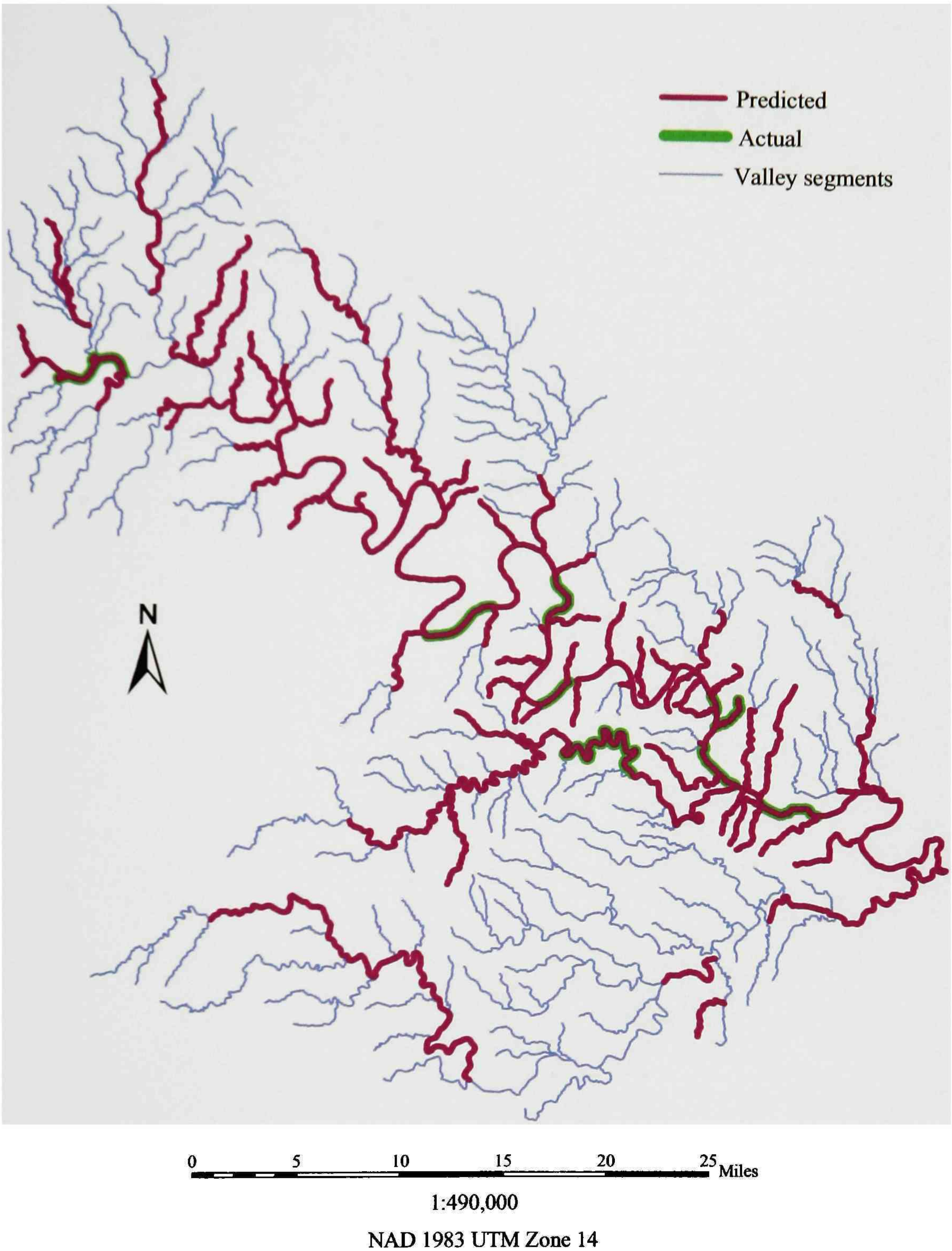

Figure 75. Species occurrence map: *Micropterus dolomieu* in the Hydrologic Unit 12090205 of Central Texas

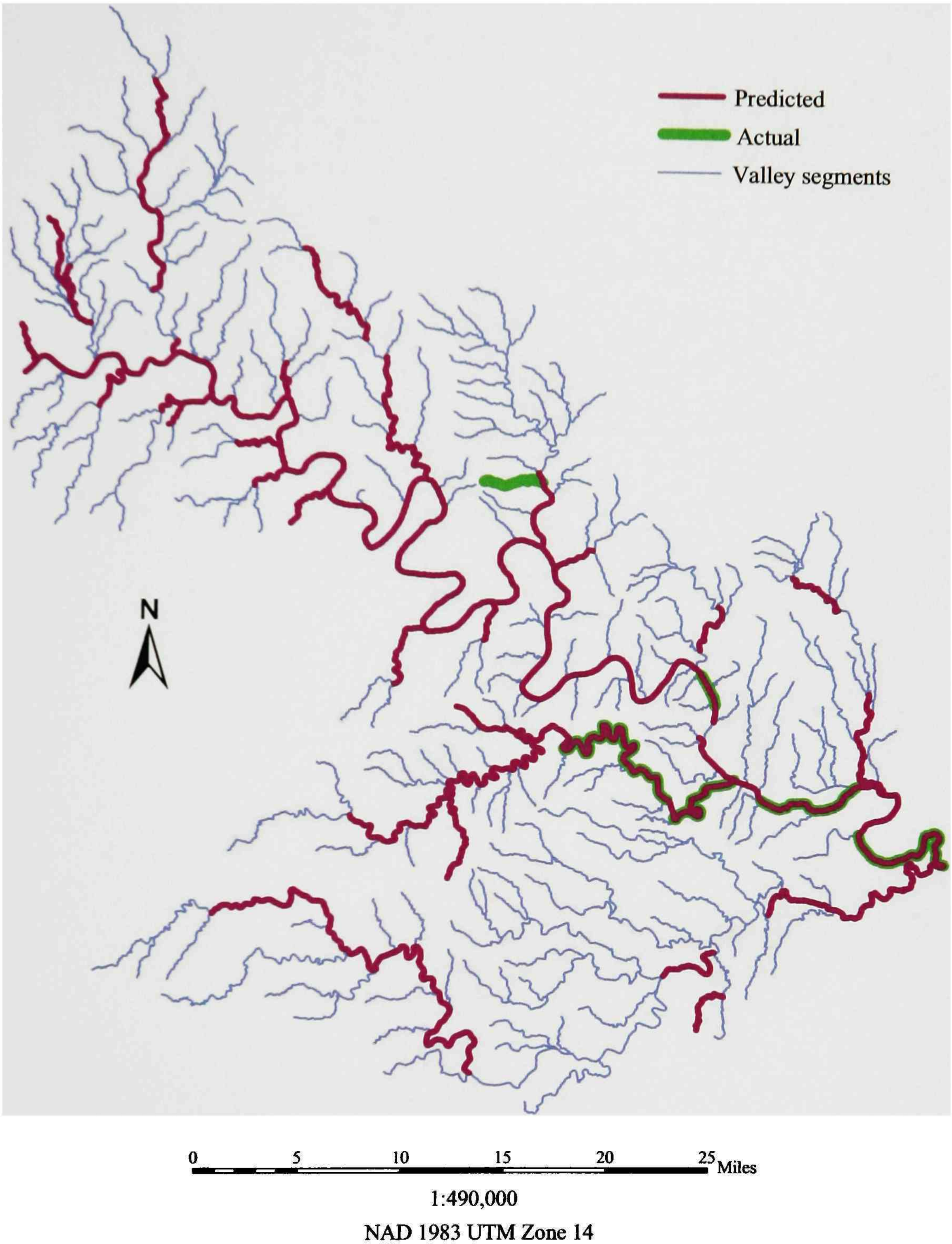

Figure 76. Species occurrence map: *Micropterus punctulatus* in the Hydrologic Unit 12090205 of Central Texas

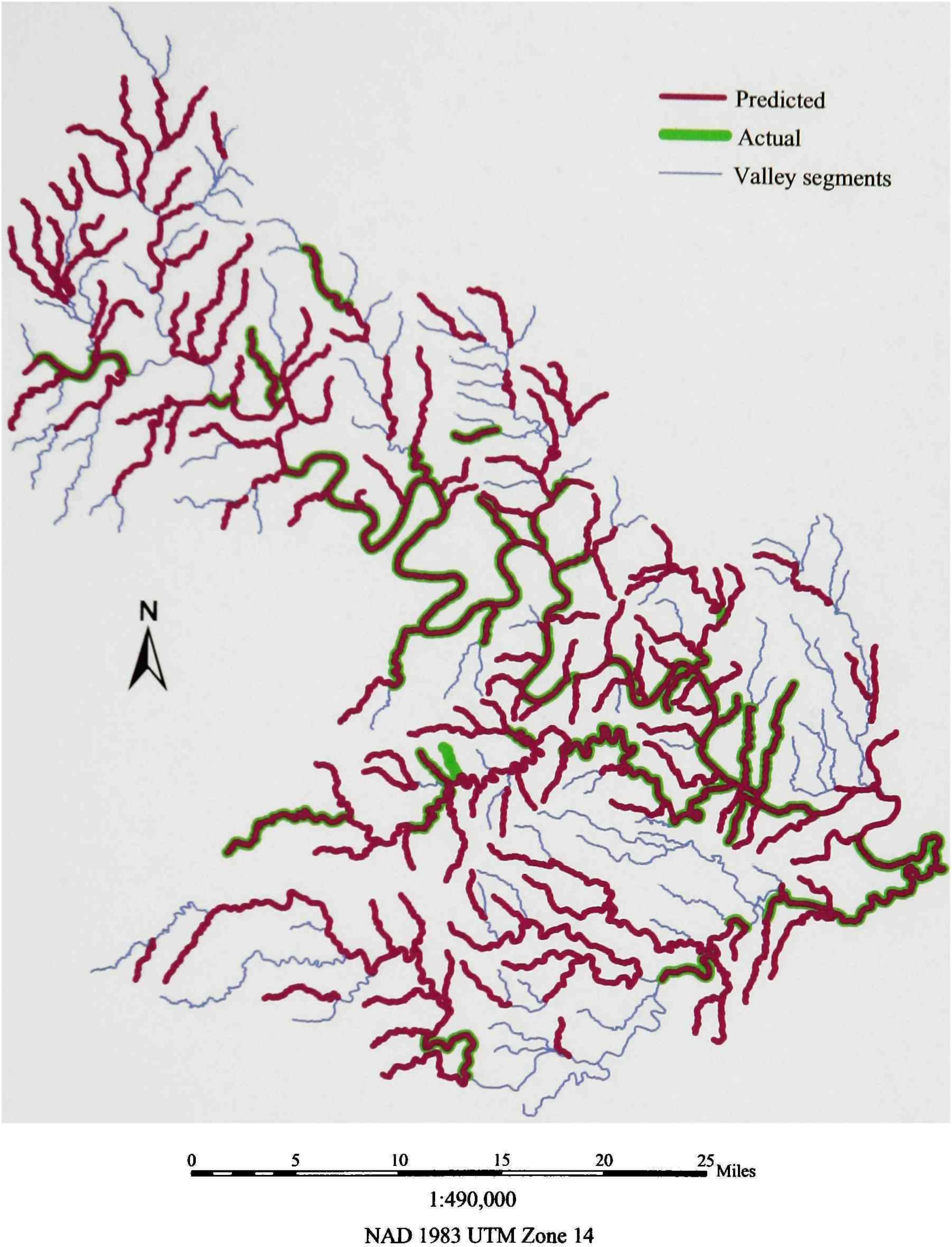

Figure 77. Species occurrence map: *Micropterus salmoides* in the Hydrologic Unit 12090205 of Central Texas

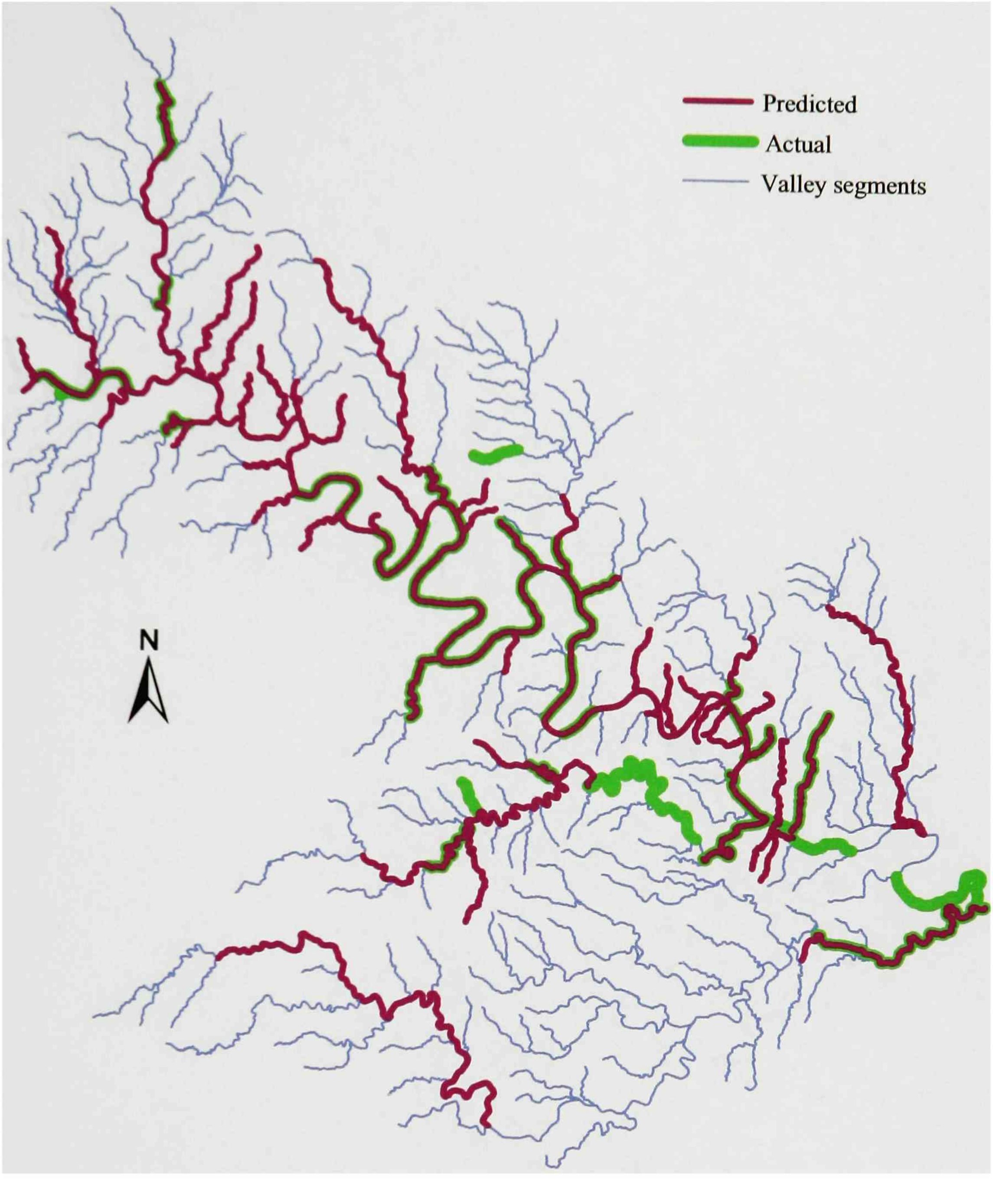

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Figure 78. Species occurrence map: *Micropterus treculii* in the Hydrologic Unit 12090205 of Central Texas

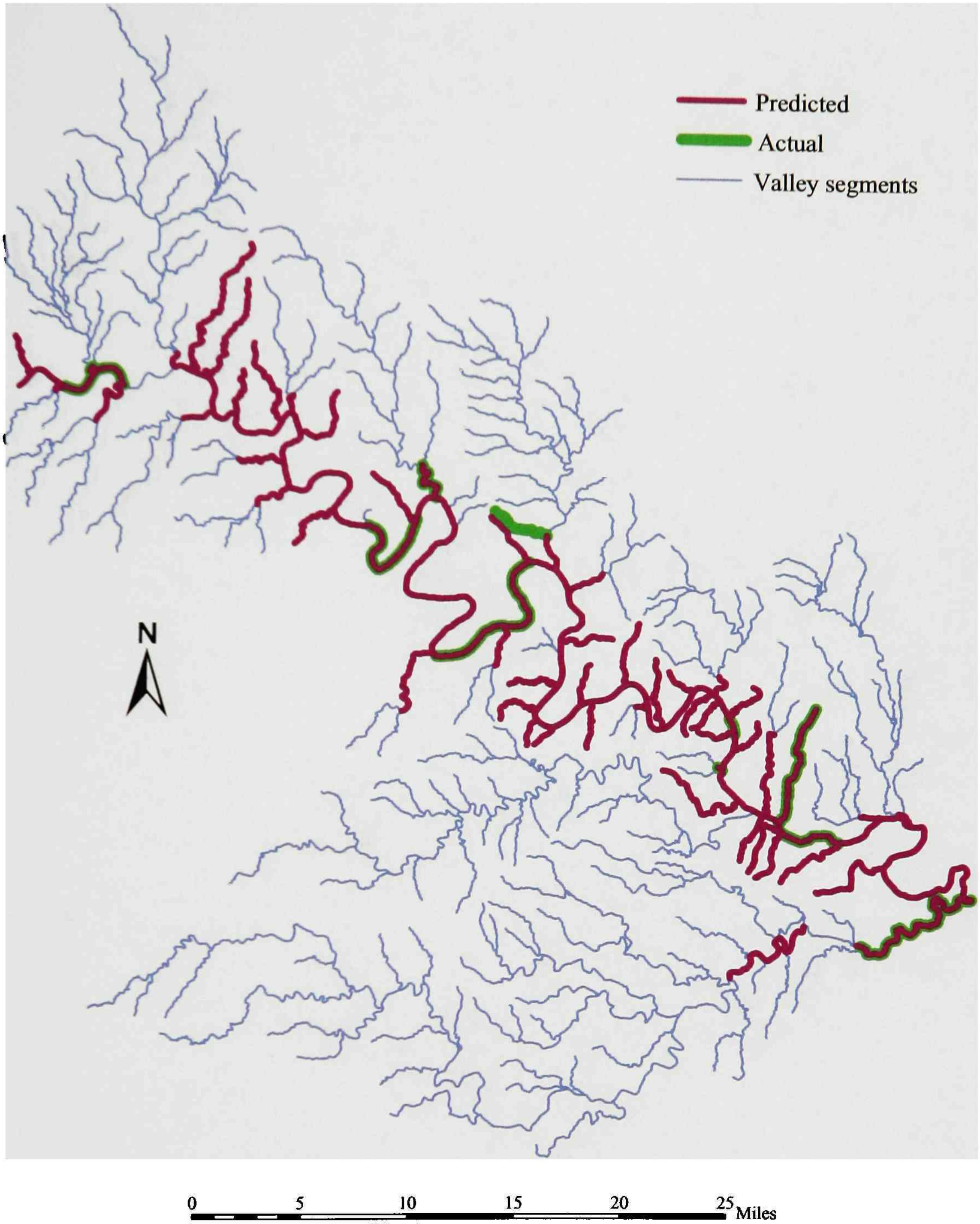


Figure 79. Species occurrence map: *Pomoxis annularis* in the Hydrologic Unit 12090205 of Central Texas

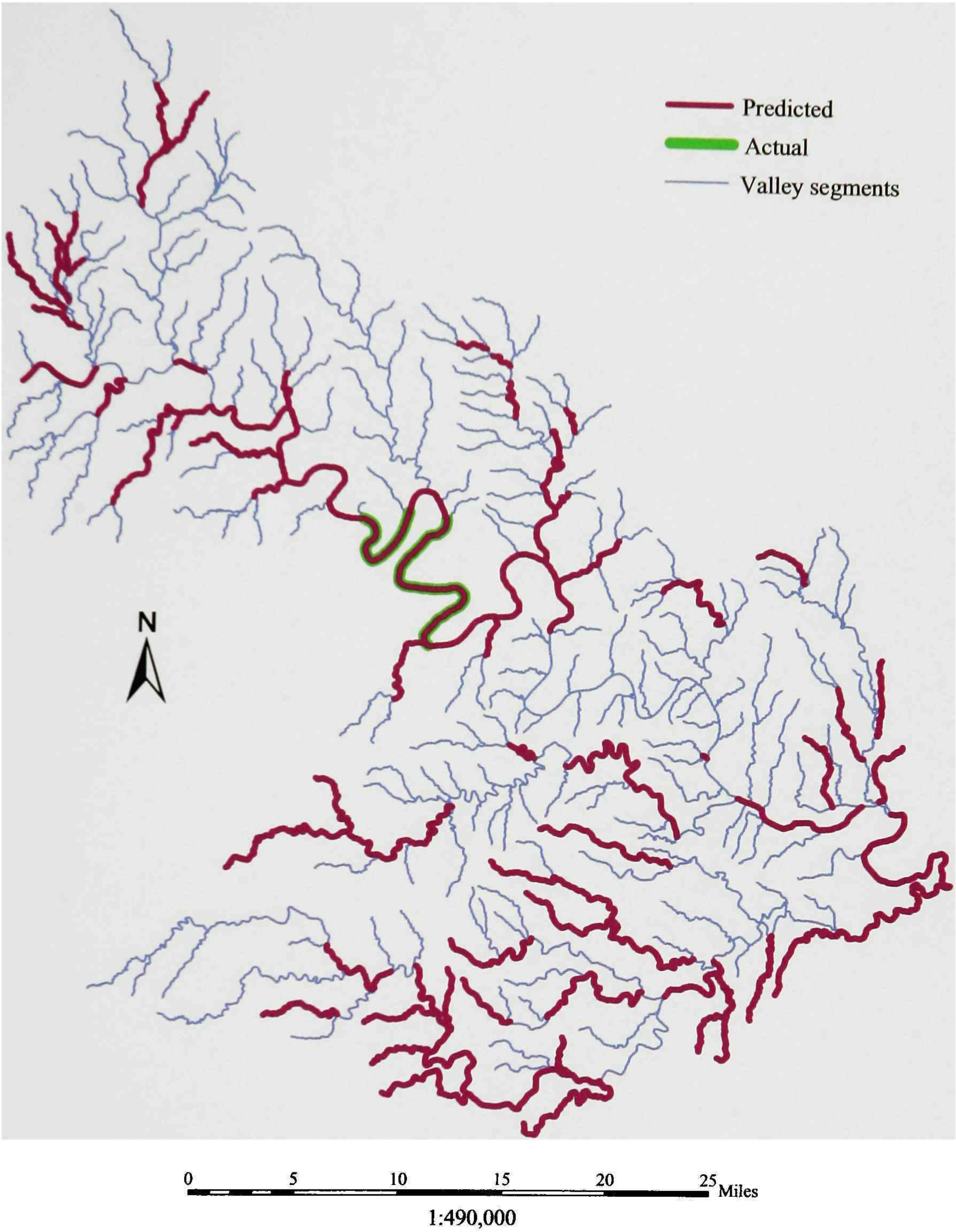


Figure 80. Species occurrence map: *Pomoxis nigromaculatus* in the Hydrologic Unit 12090205 of Central Texas

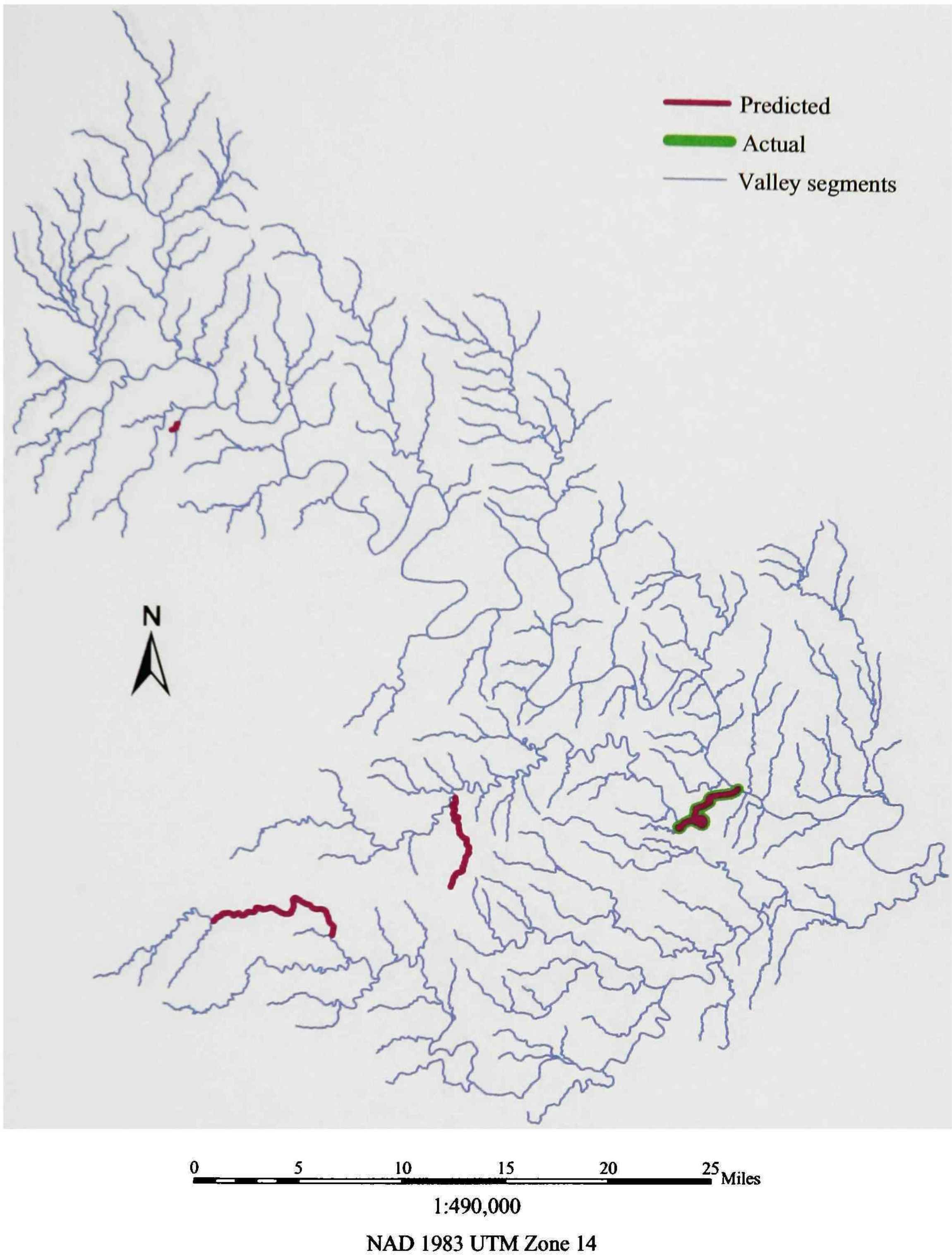


Figure 81. Species occurrence map: *Etheostoma grahami* in the Hydrologic Unit 12090205 of Central Texas

Figure 82. Species occurrence map: *Etheostoma chlorosoma* in the Hydrologic Unit 12090205 of Central Texas

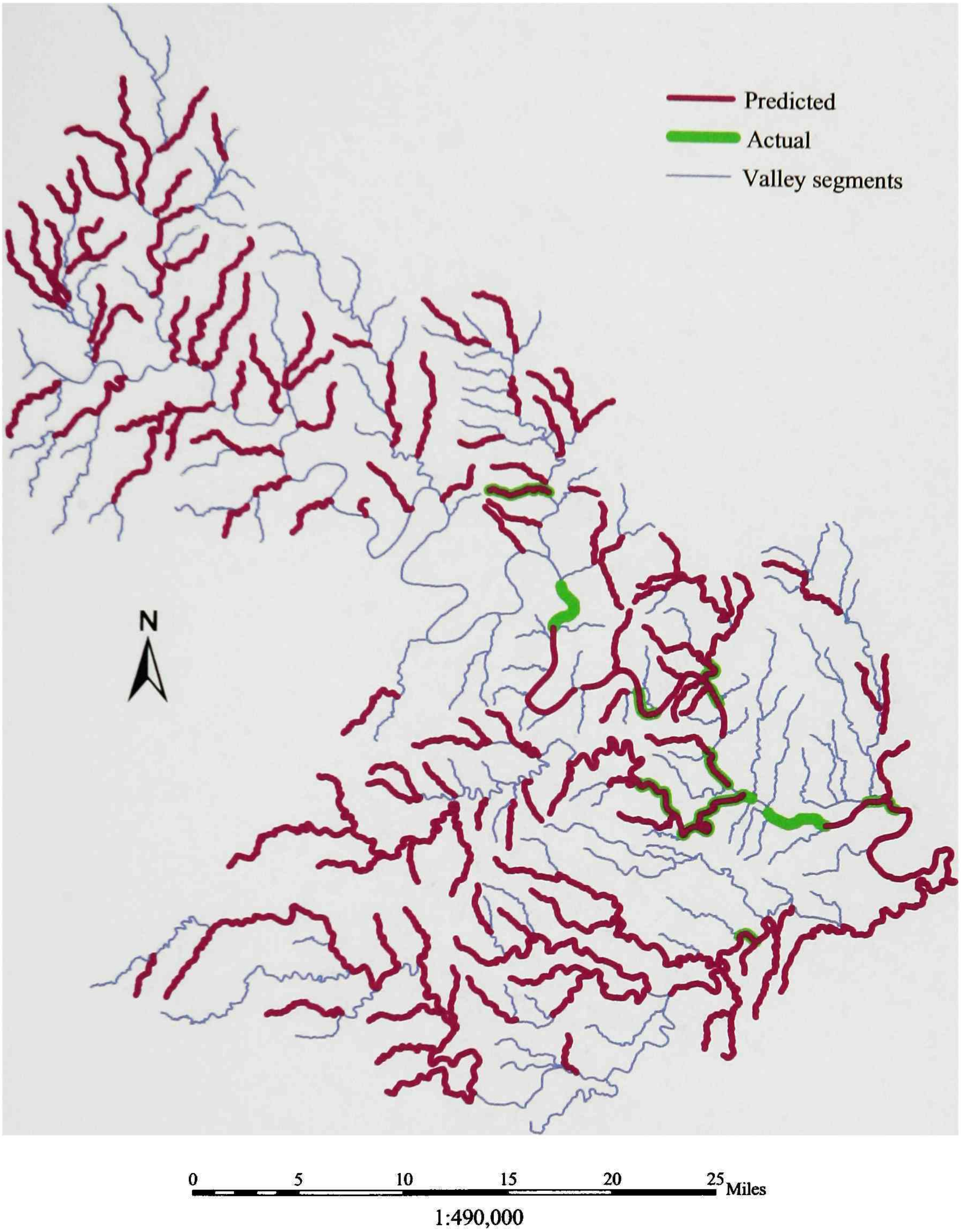


Figure 83. Species occurrence map: *Etheostoma lepidum* in the Hydrologic Unit 12090205 of Central Texas

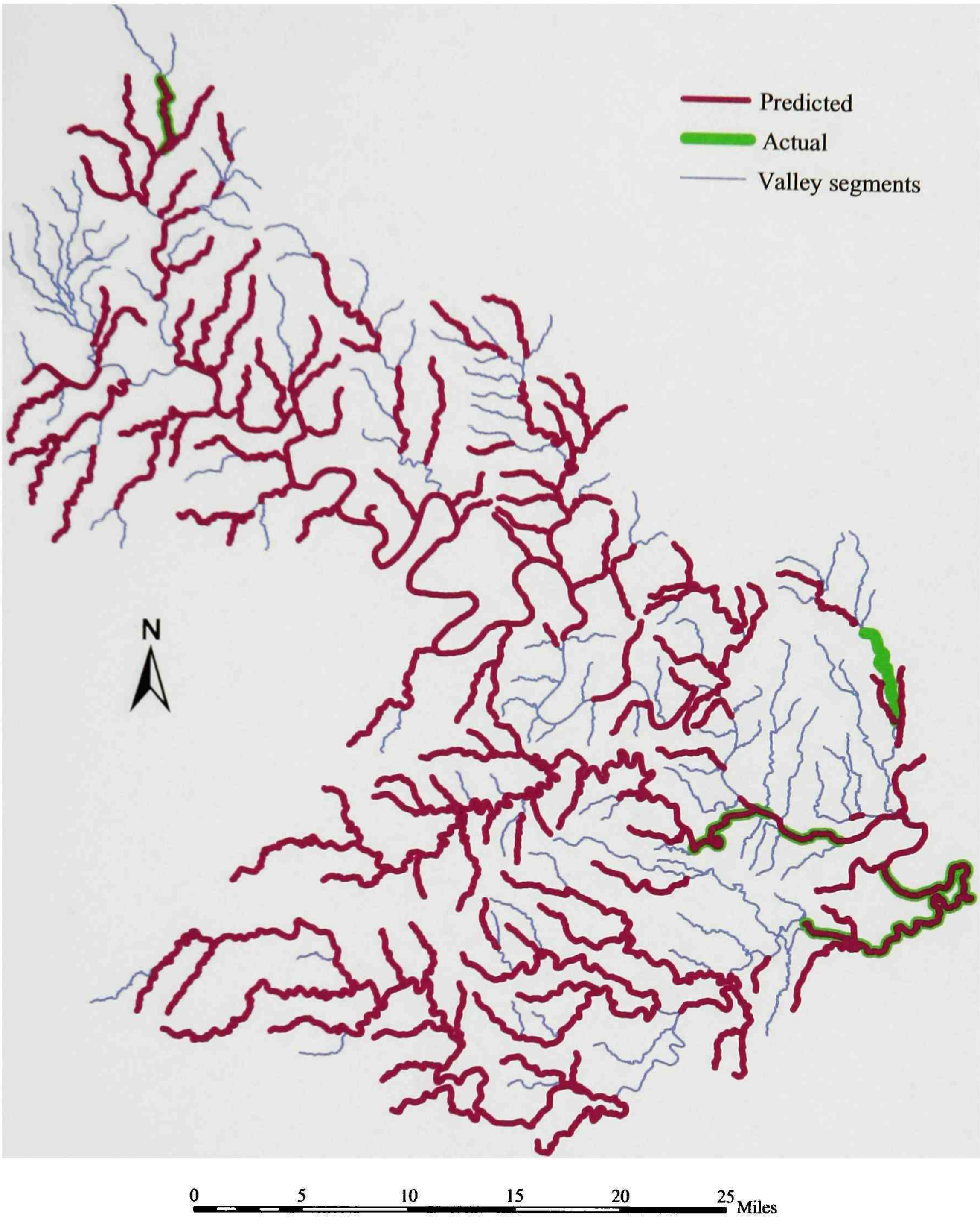


Figure 84. Species occurrence map: *Etheostoma spectabile* in the Hydrologic Unit 12090205 of Central Texas

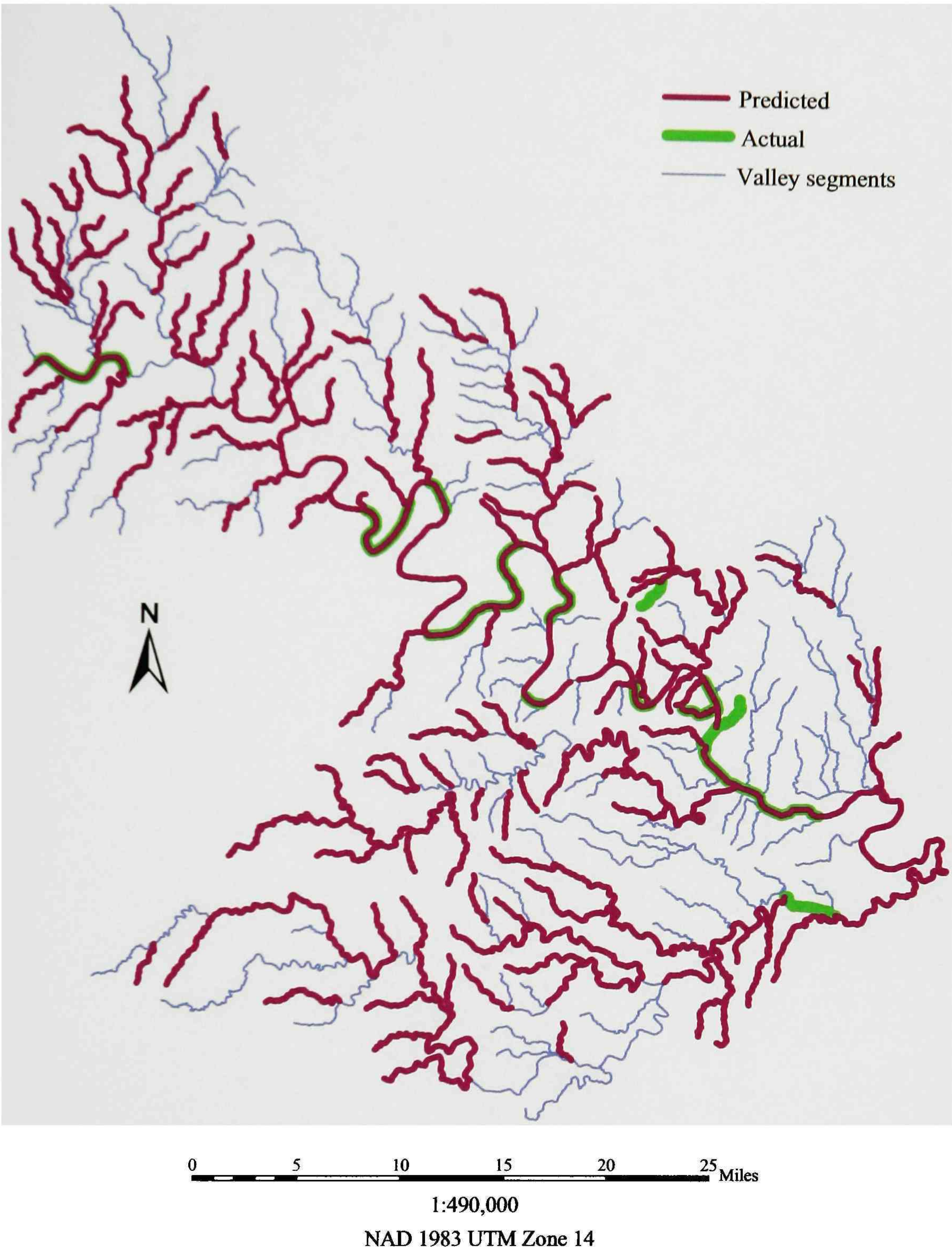


Figure 85. Species occurrence map: *Percina caprodes* in the Hydrologic Unit 12090205 of Central Texas

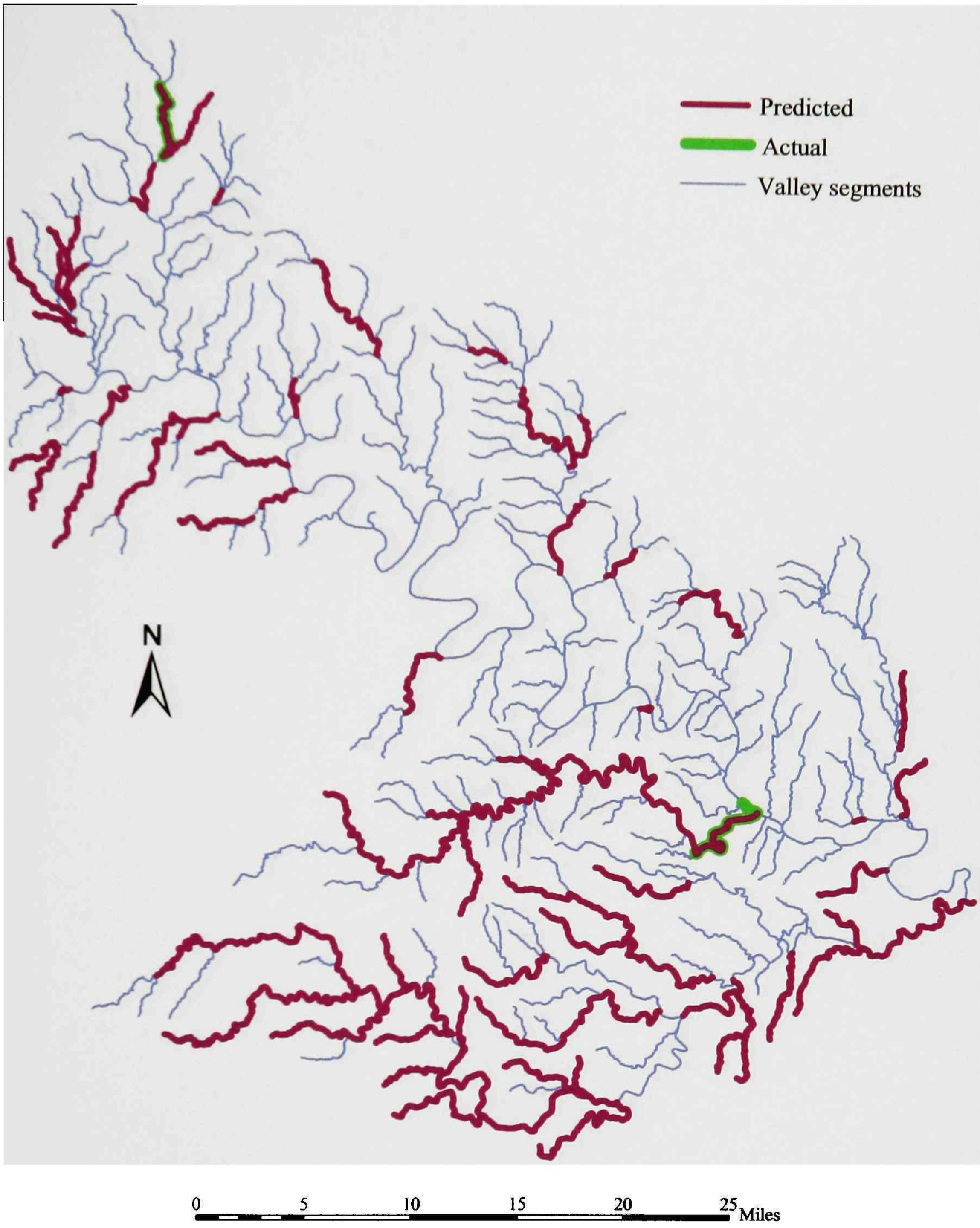


Figure 86. Species occurrence map: *Percina carbonaria* in the Hydrologic Unit 12090205 of Central Texas

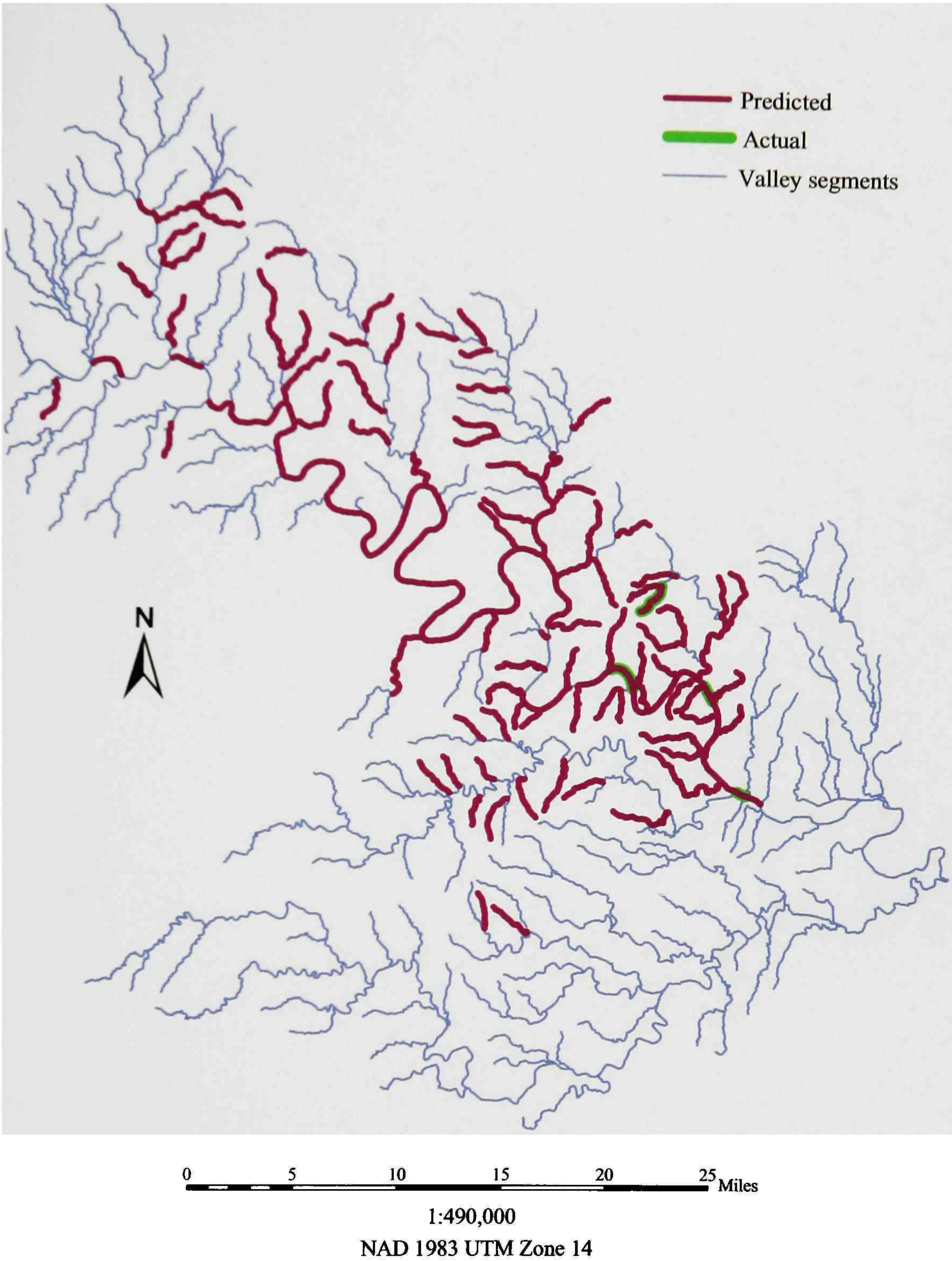


Figure 87. Species occurrence map: *Percina macrolepida* in the Hydrologic Unit 12090205 of Central Texas

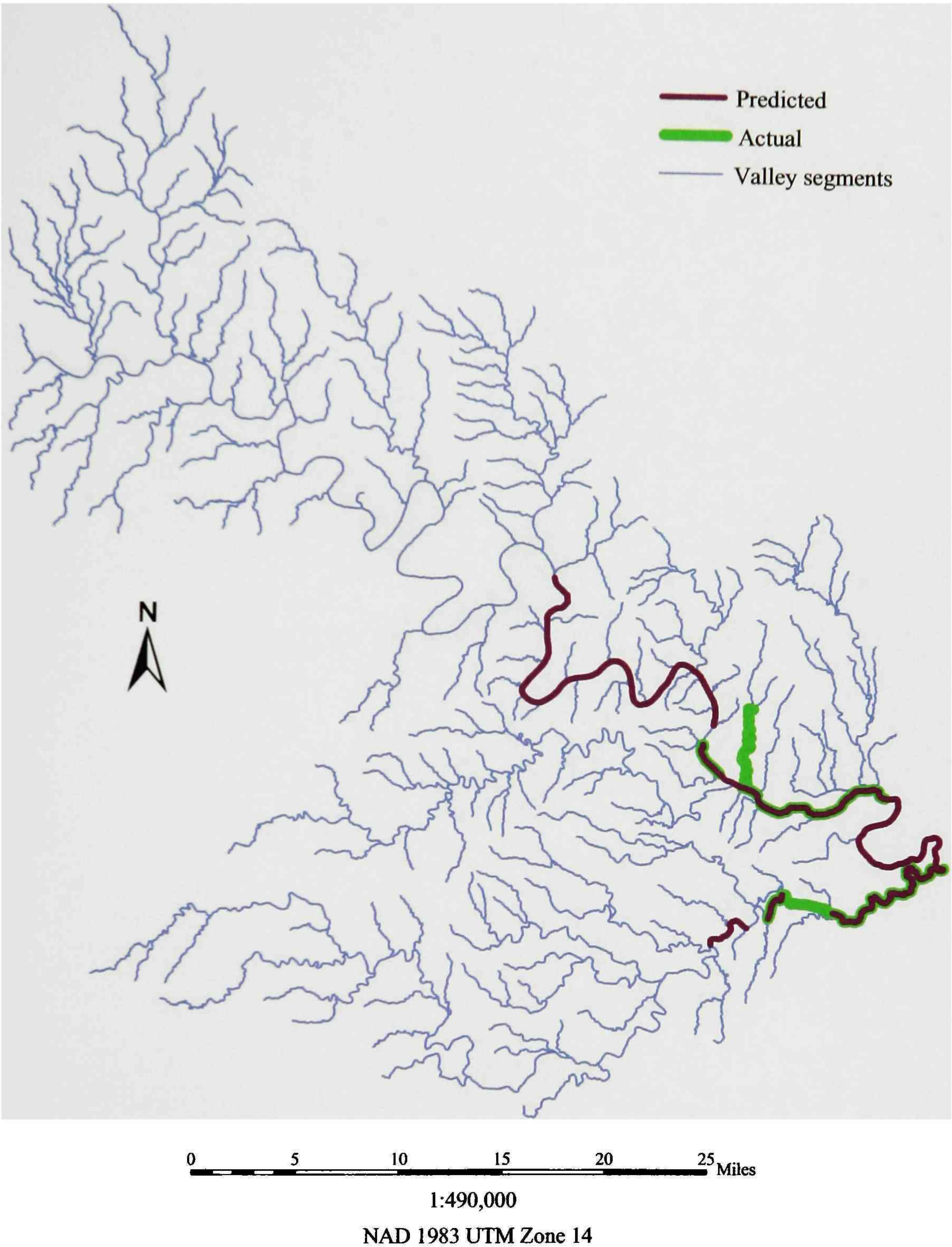


Figure 88. Species occurrence map: *Percina sciera* in the Hydrologic Unit 12090205 of Central Texas

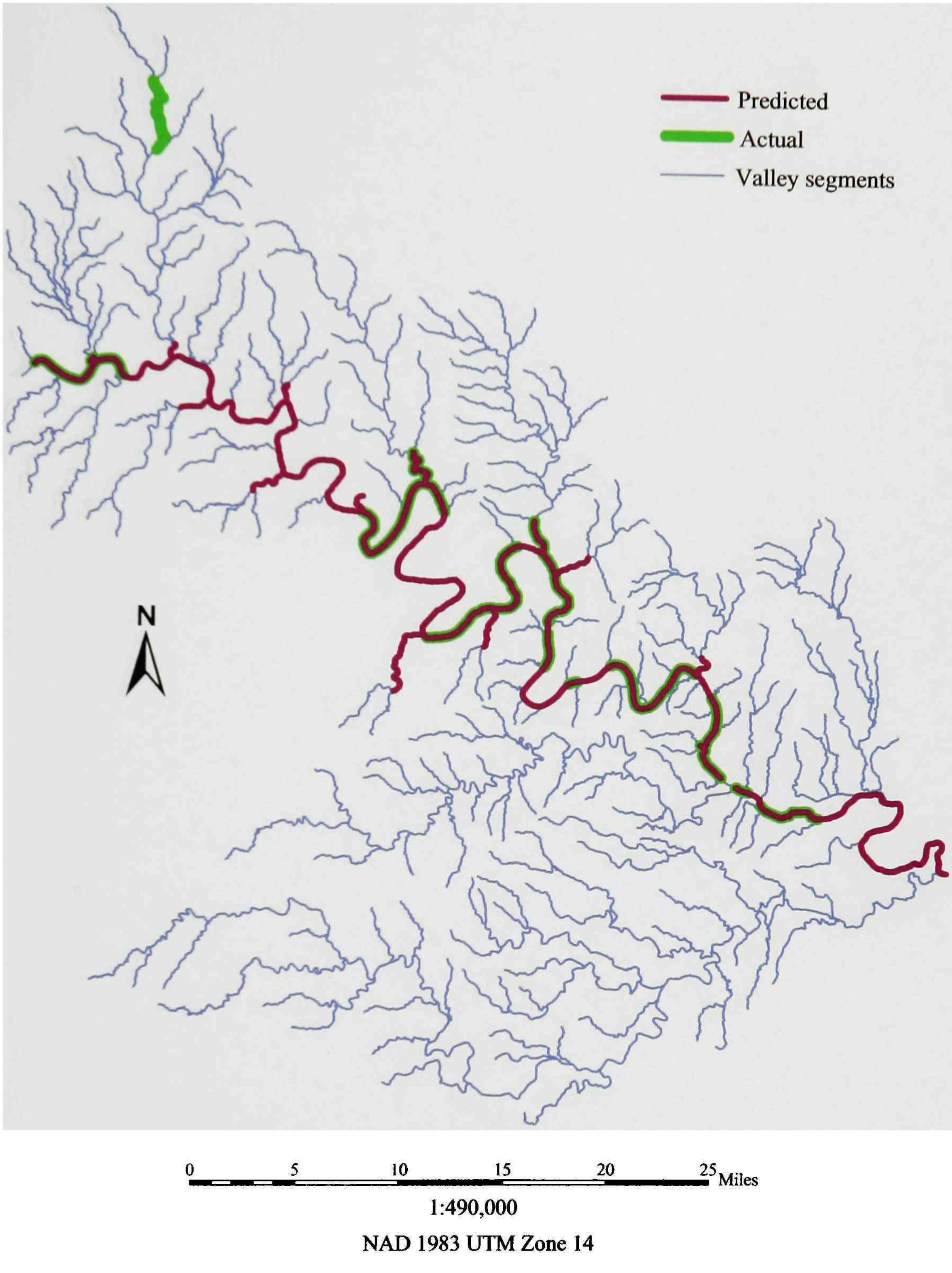


Figure 89. Species occurrence map: *Aplodinotus grunniens* in the Hydrologic Unit 12090205 of Central Texas

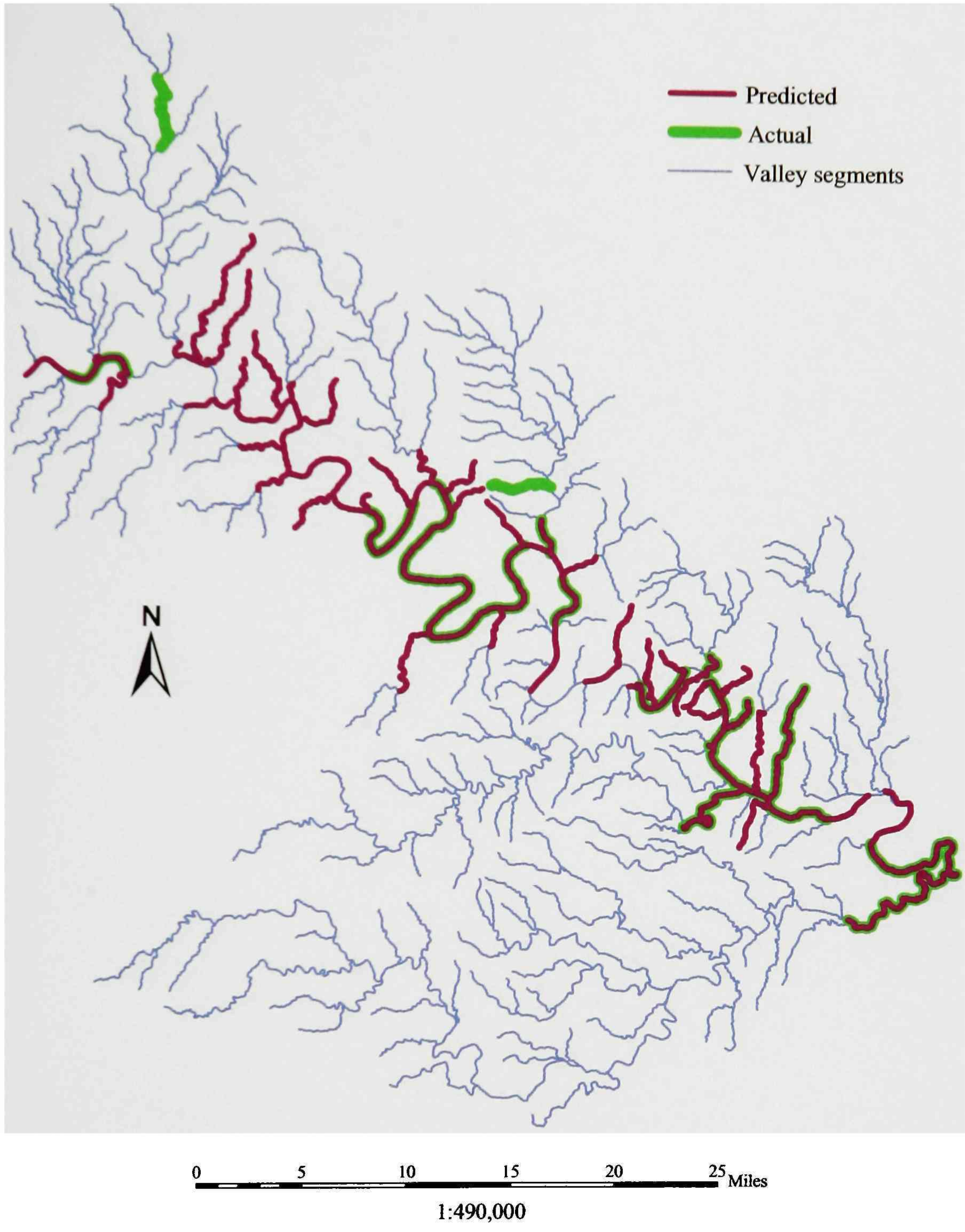


Figure 90. Species occurrence map: *Cichlasoma cyanoguttatum* in the Hydrologic Unit 12090205 of Central Texas

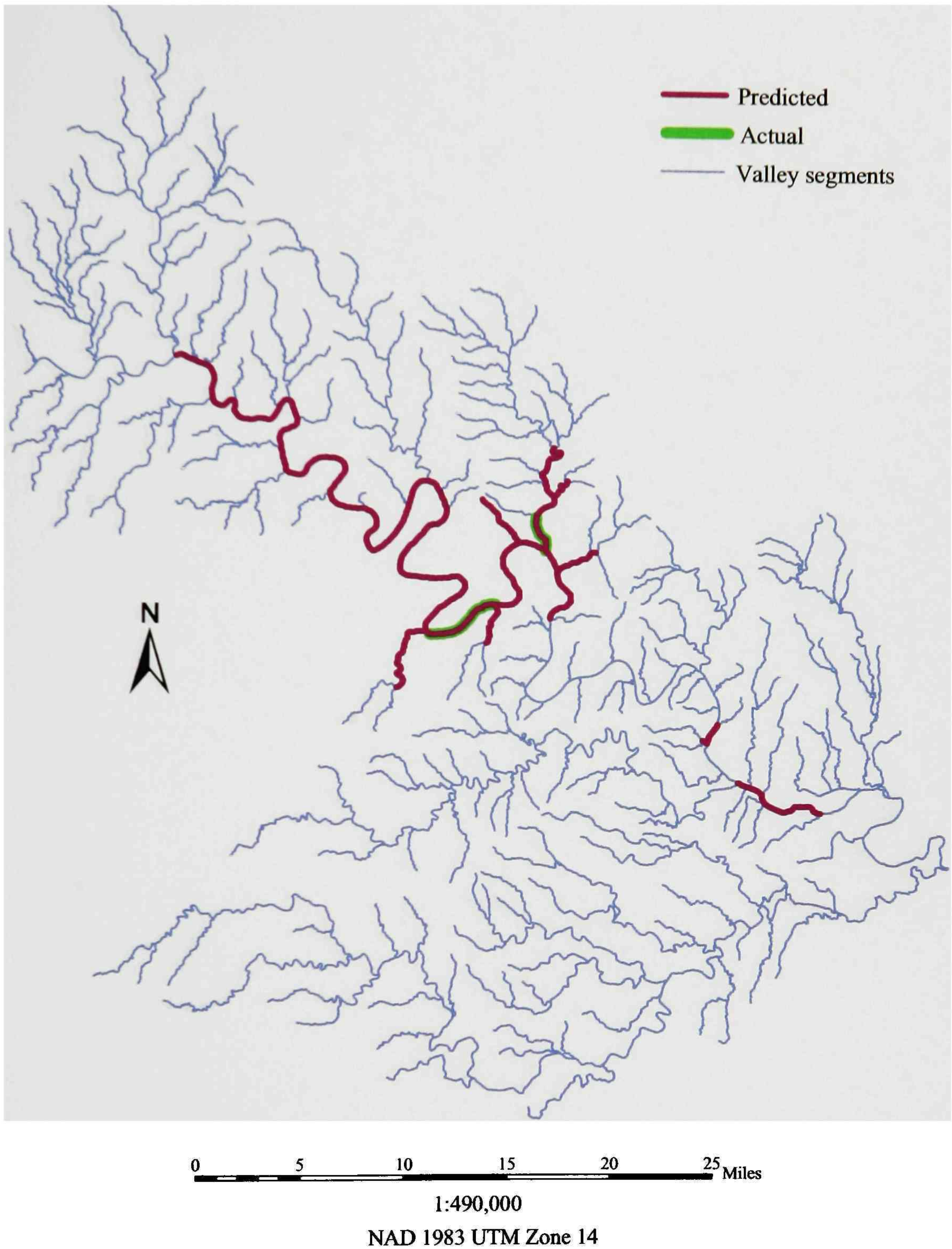
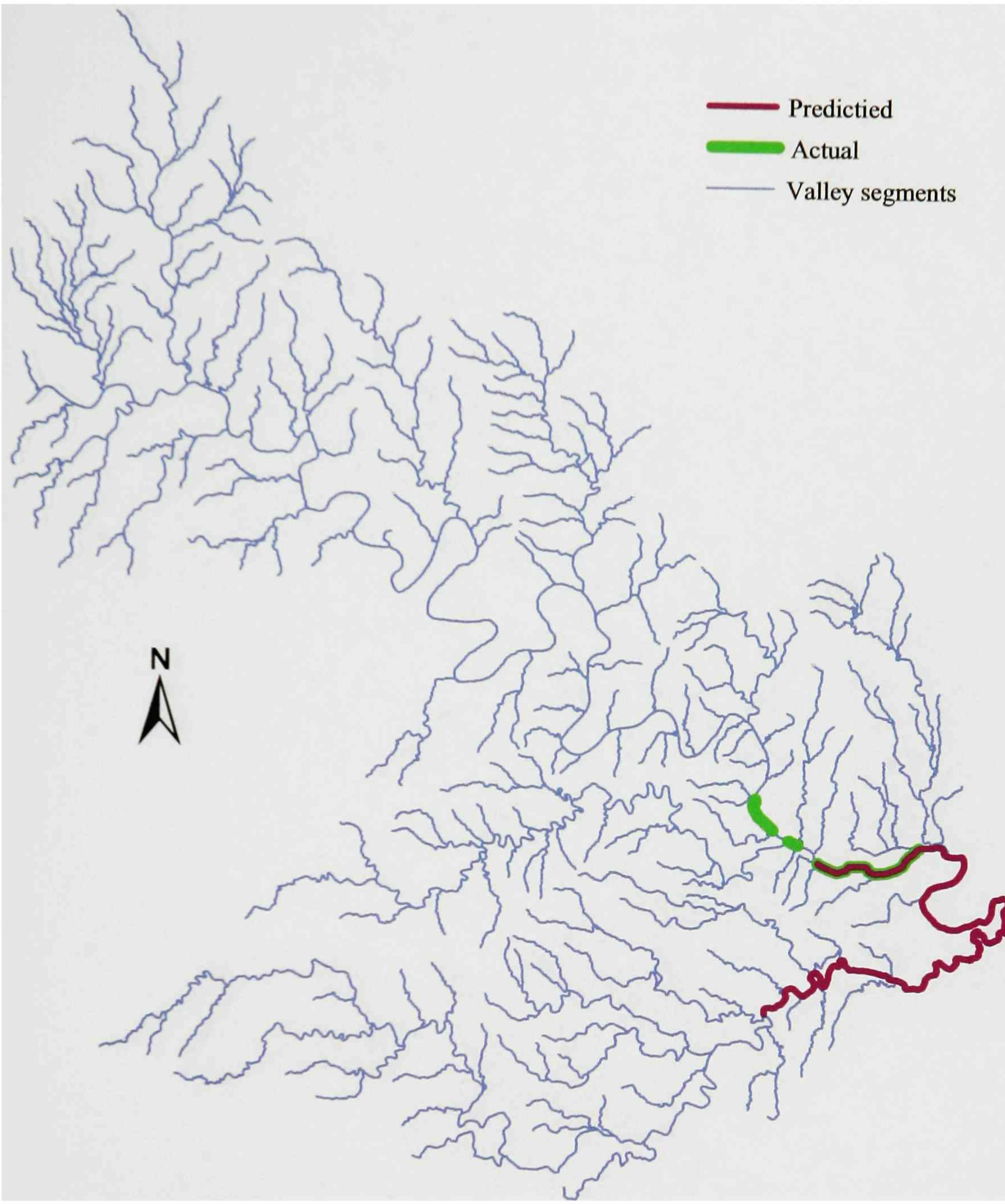


Figure 91. Species occurrence map: *Oreochromis aureus* in the Hydrologic Unit 12090205 of Central Texas



0 5 10 15 20 25 Miles

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Figure 92. Species occurrence map: *Mugil cephalus* in the Hydrologic Unit 12090205 of Central Texas

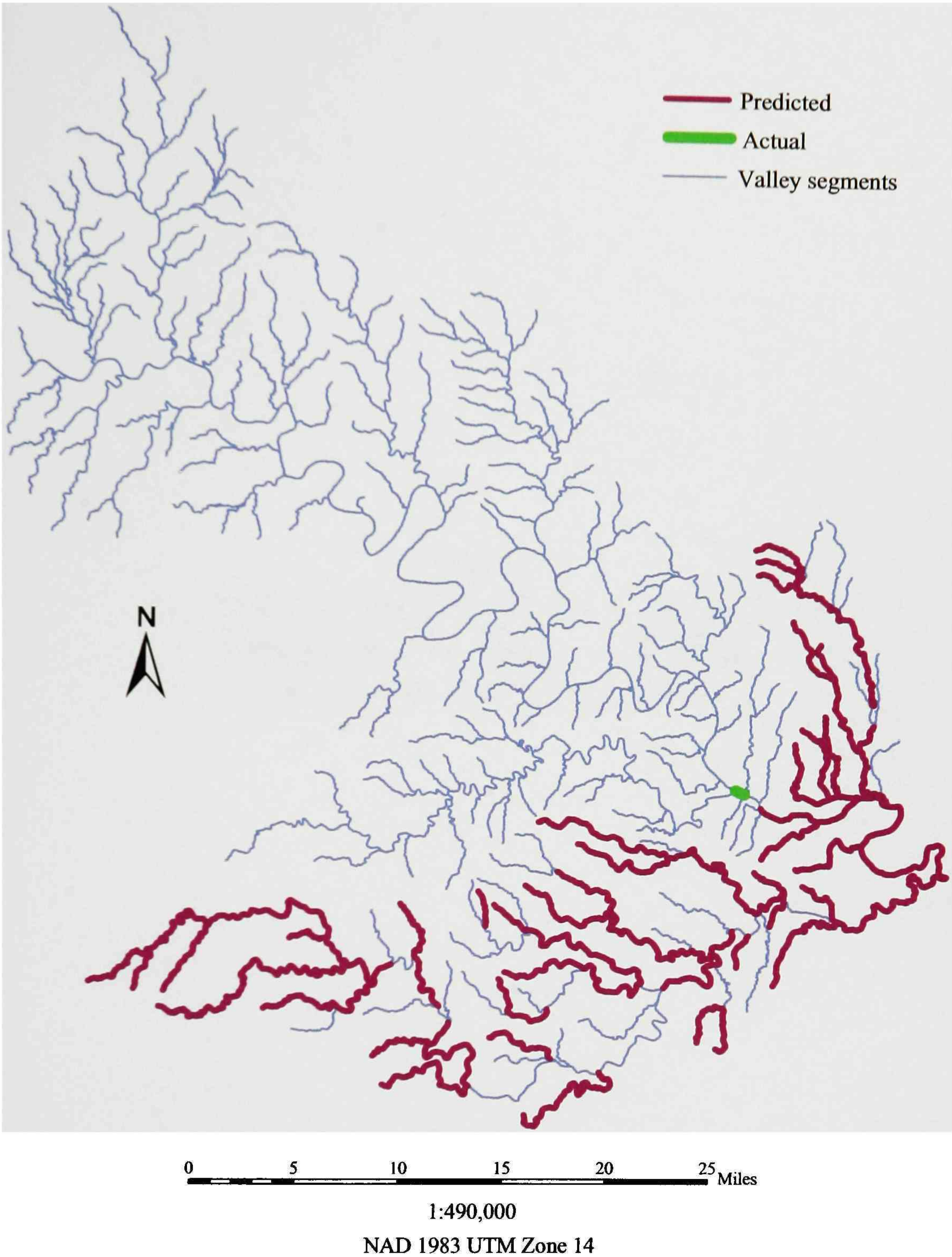


Figure 93. Species occurrence map: *Mugil curema* in the Hydrologic Unit 12090205 of Central Texas

APPENDIX D

PREDICTED DISTRIBUTION OF FISH IN THE HYDROLOGIC UNIT 12090205 OF CENTRAL TEXAS USING LOGISTIC REGRESSION

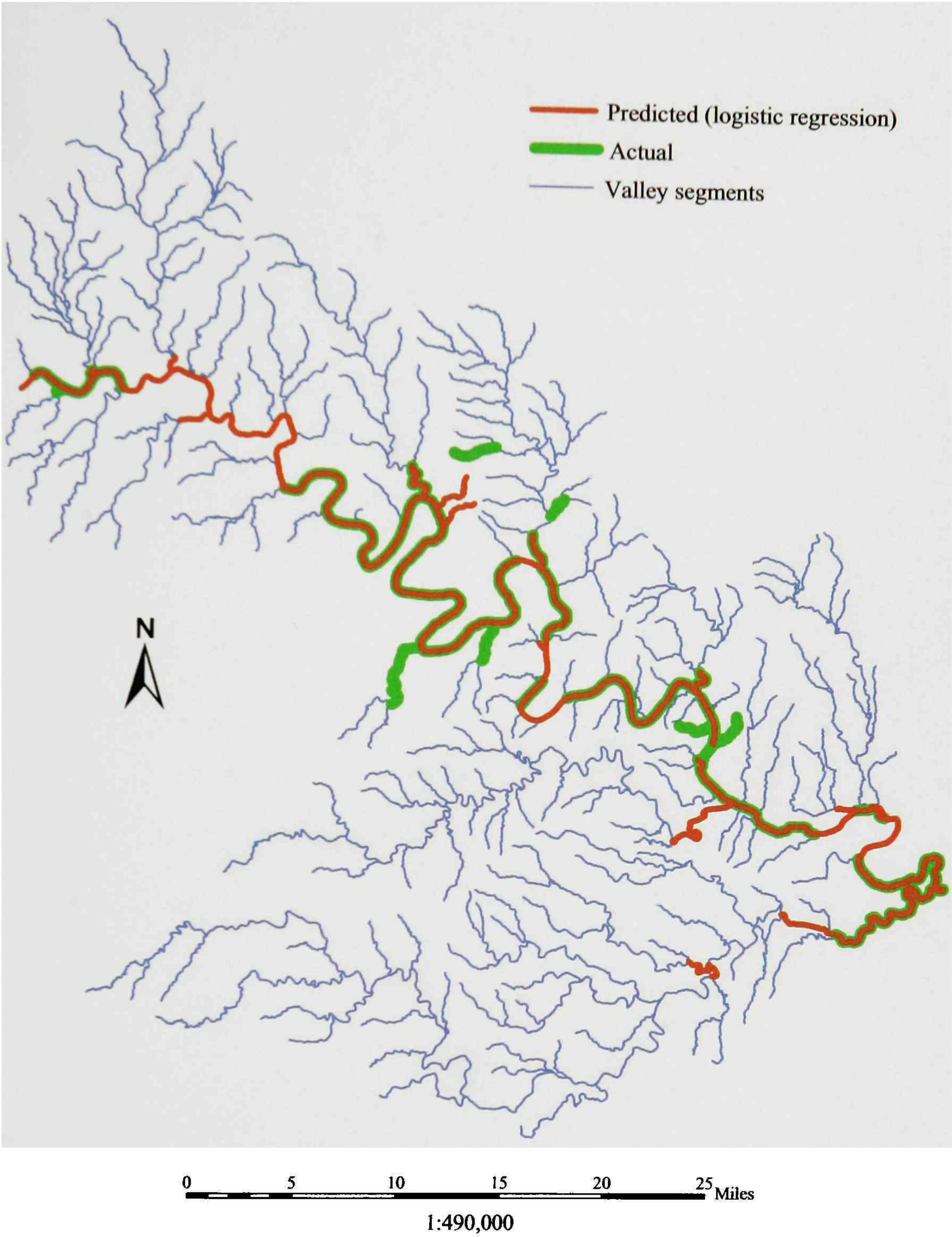


Figure 94. Predicted occurrence of *Dorosoma cepedianum* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

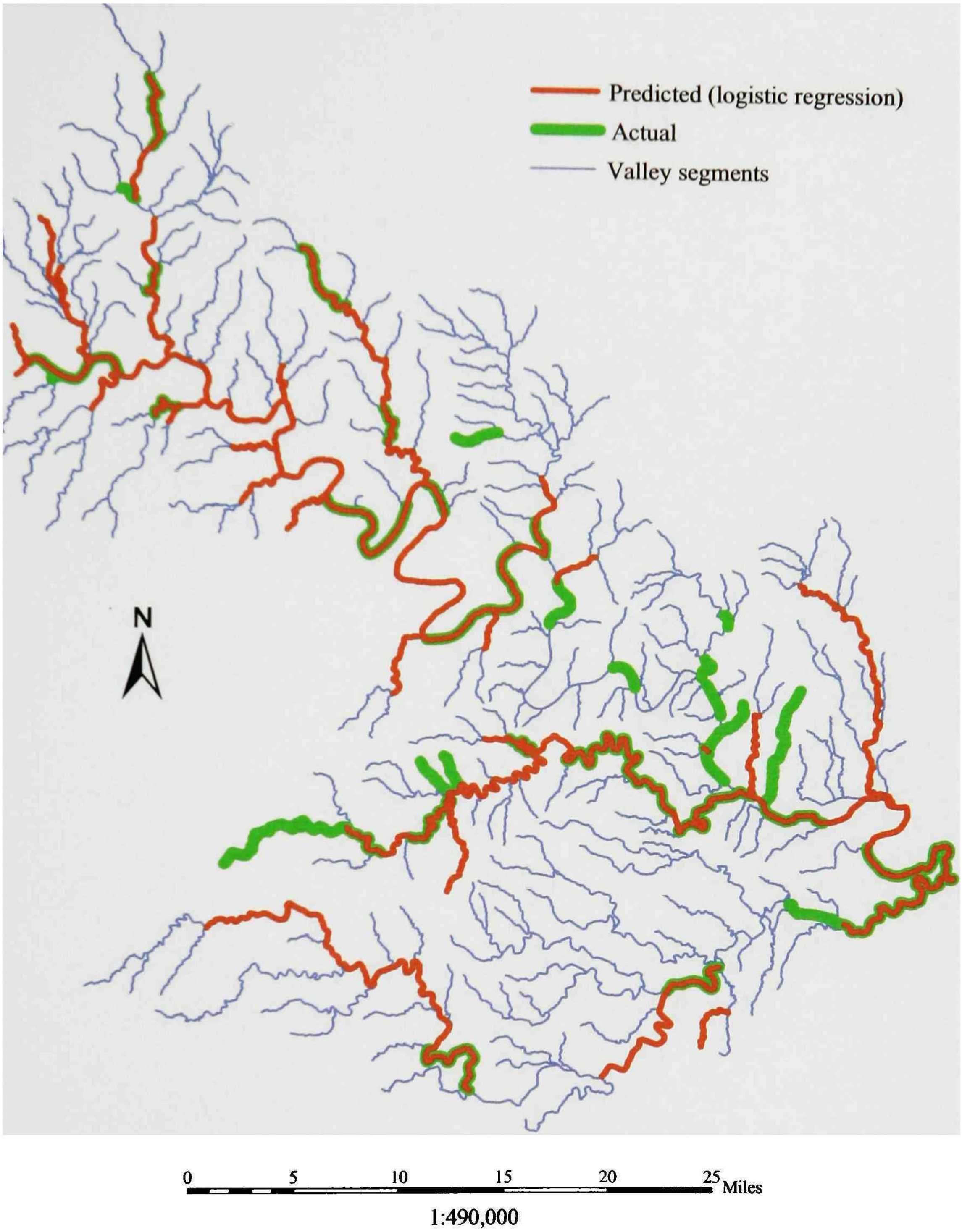


Figure 95. Predicted occurrence of *Cyprinella venusta* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

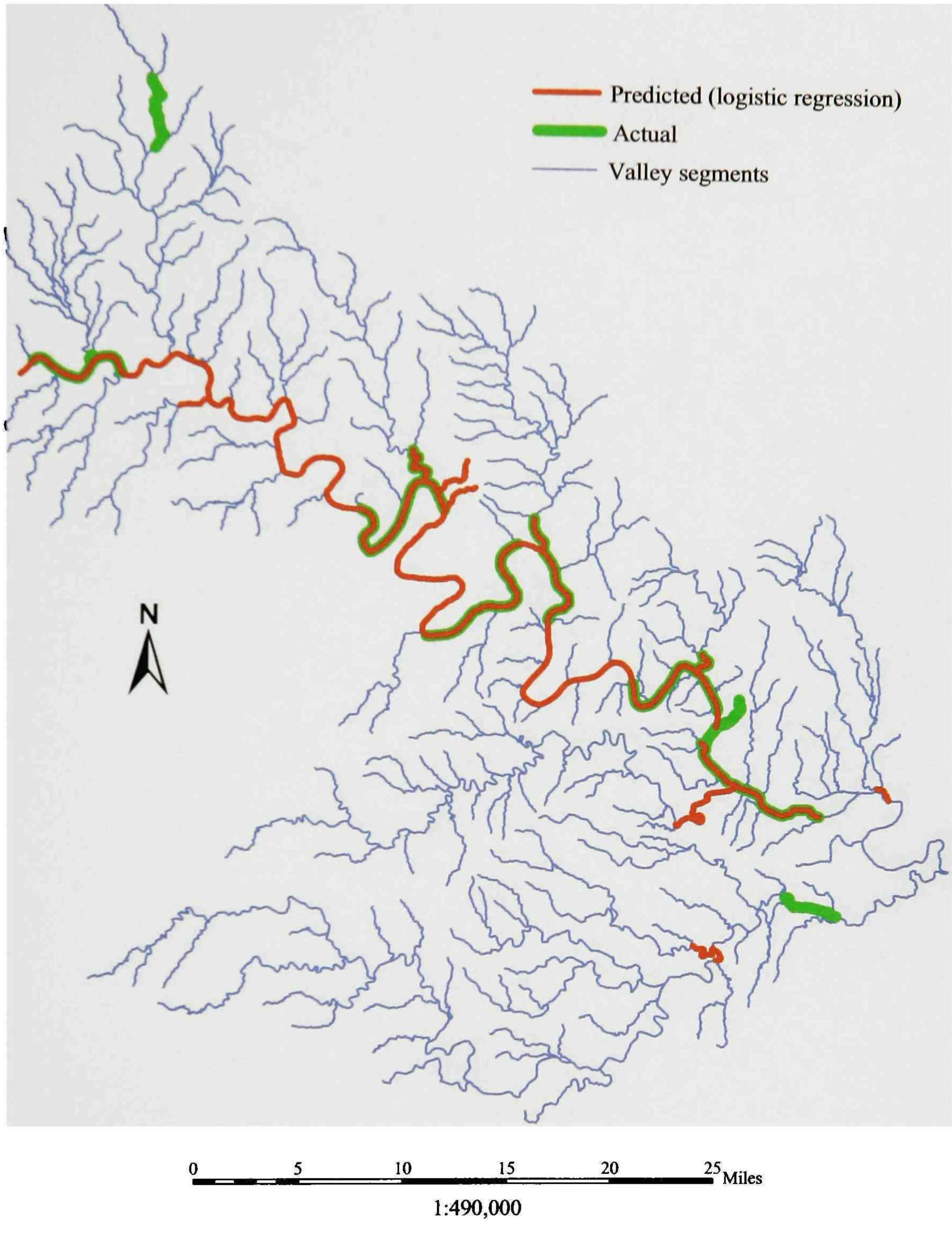


Figure 96. Predicted occurrence of *Cyprinus carpio* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

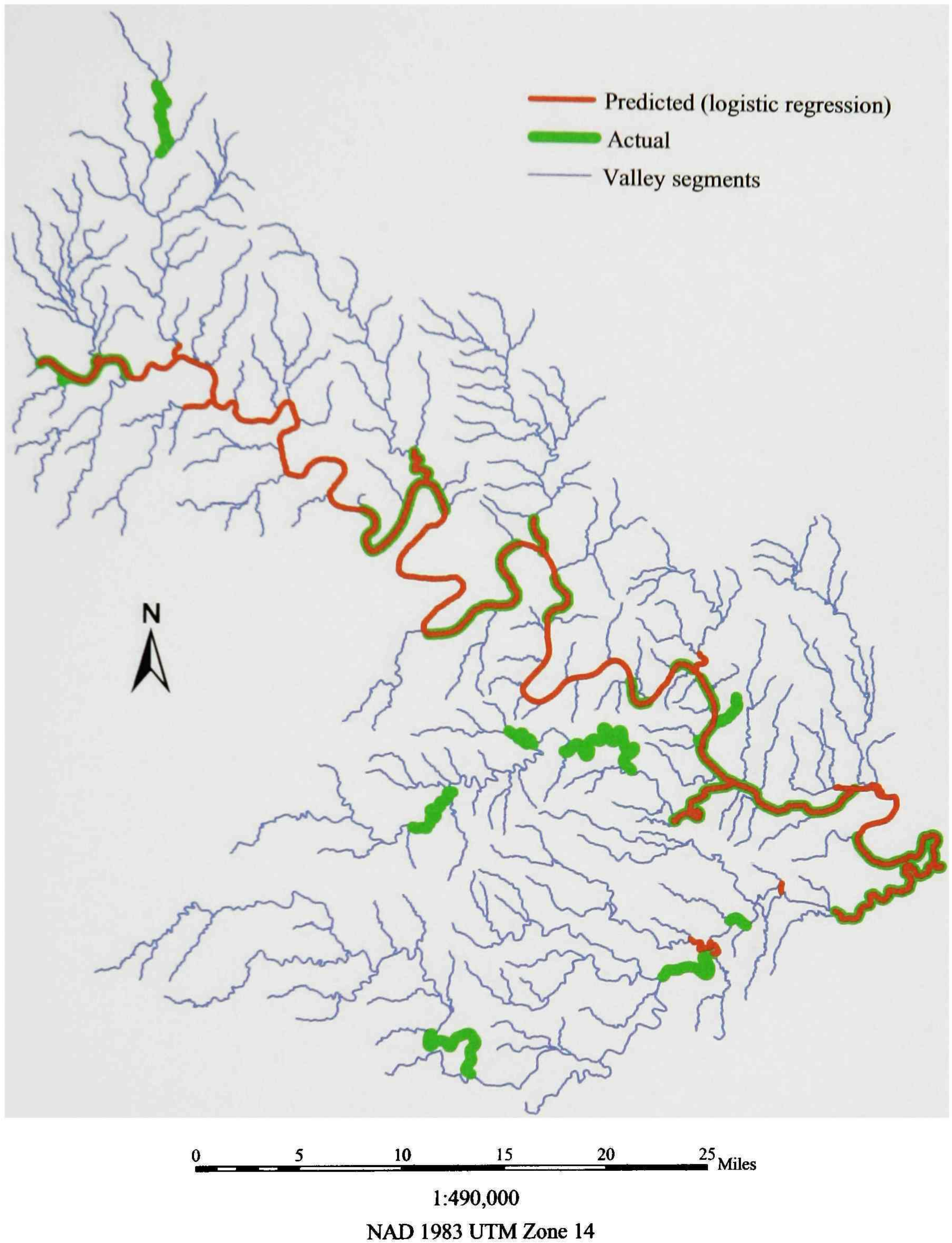
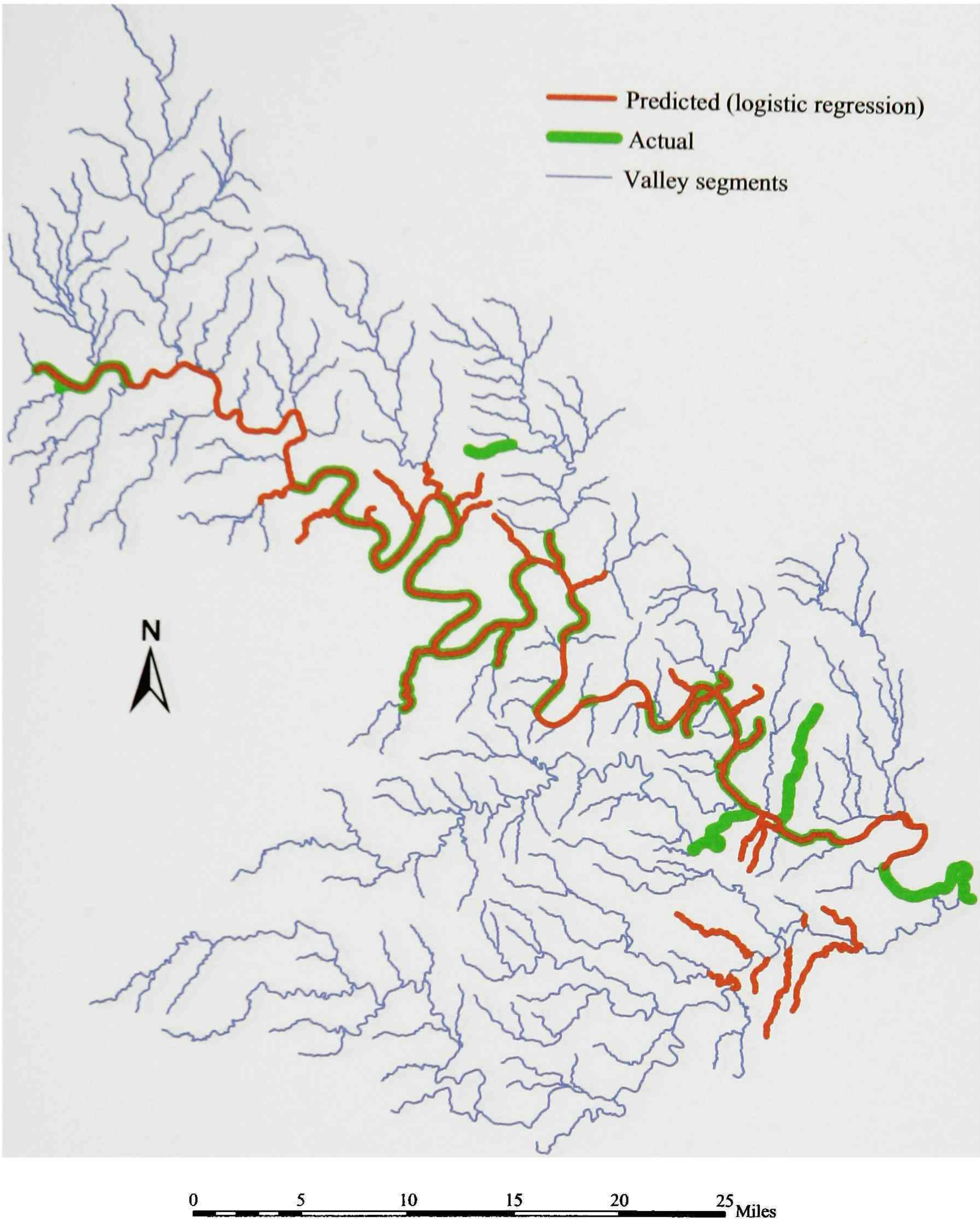


Figure 97. Predicted occurrence of *Ictalurus punctatus* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas



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NAD 1983 UTM Zone 14

Figure 98. Predicted occurrence of *Menidia beryllina* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

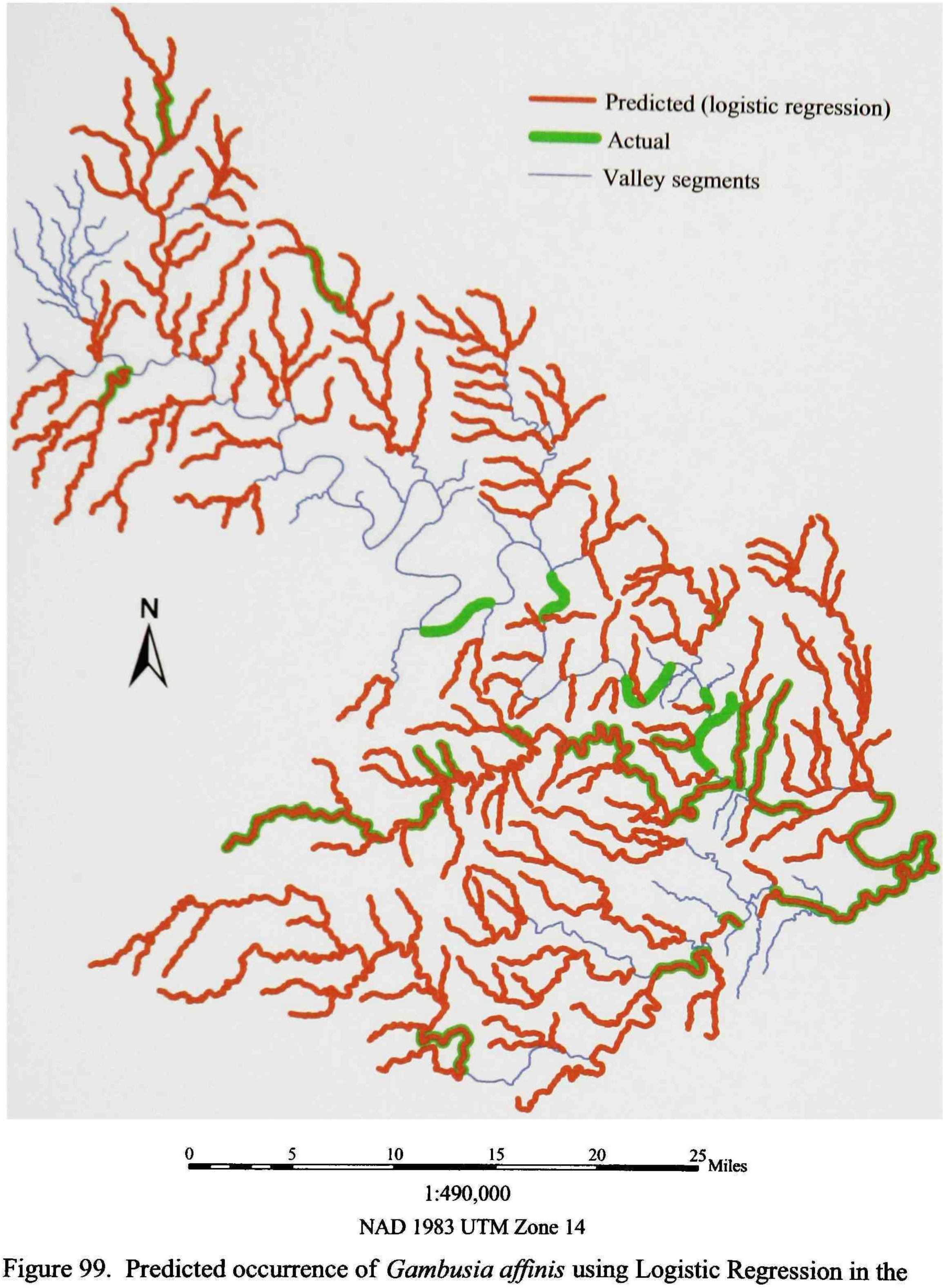

Figure 99. Predicted occurrence of *Gambusia affinis* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

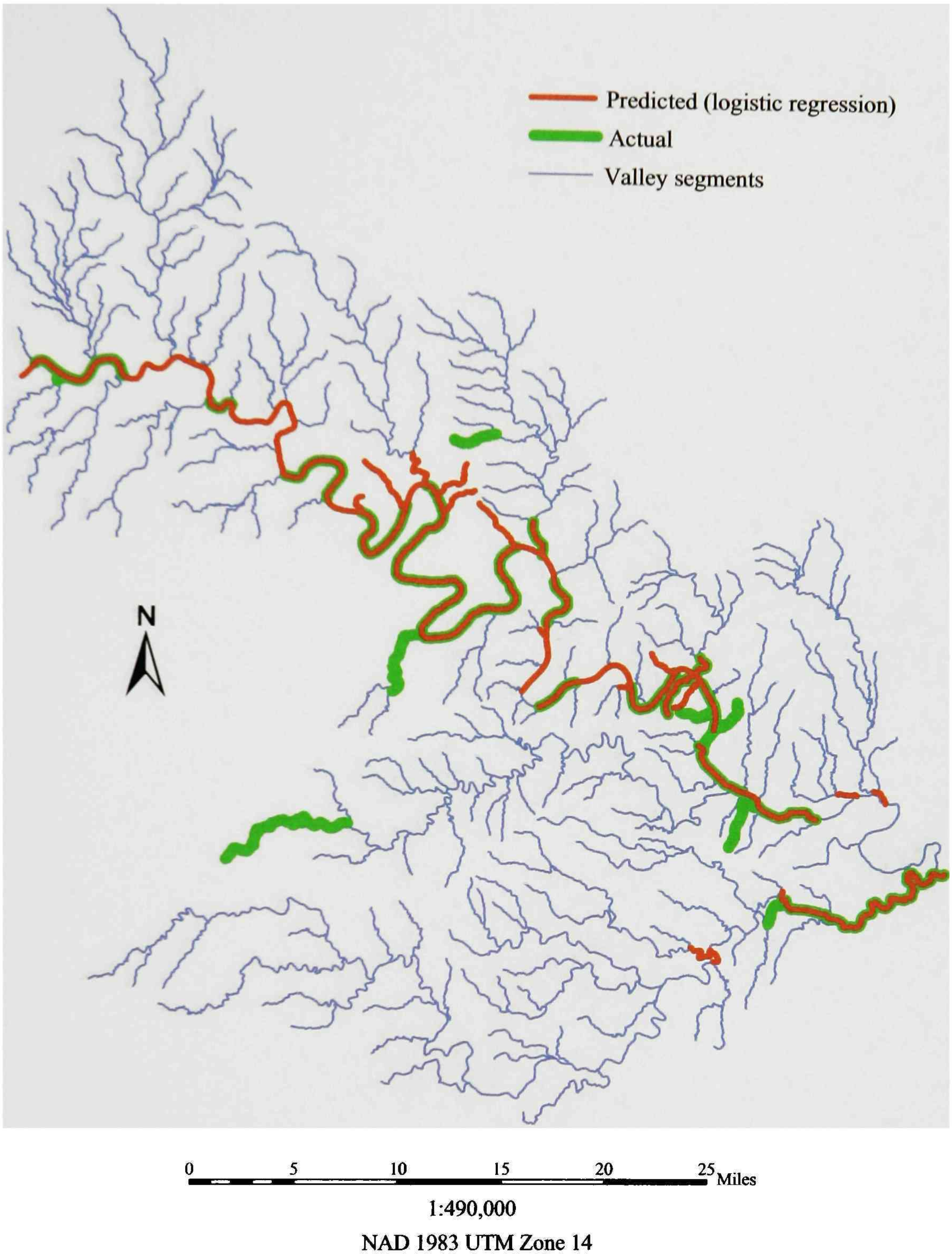

Figure 100. Predicted occurrence of *Chaenobryttus gulosus* (*Lepomis gulosus*) using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

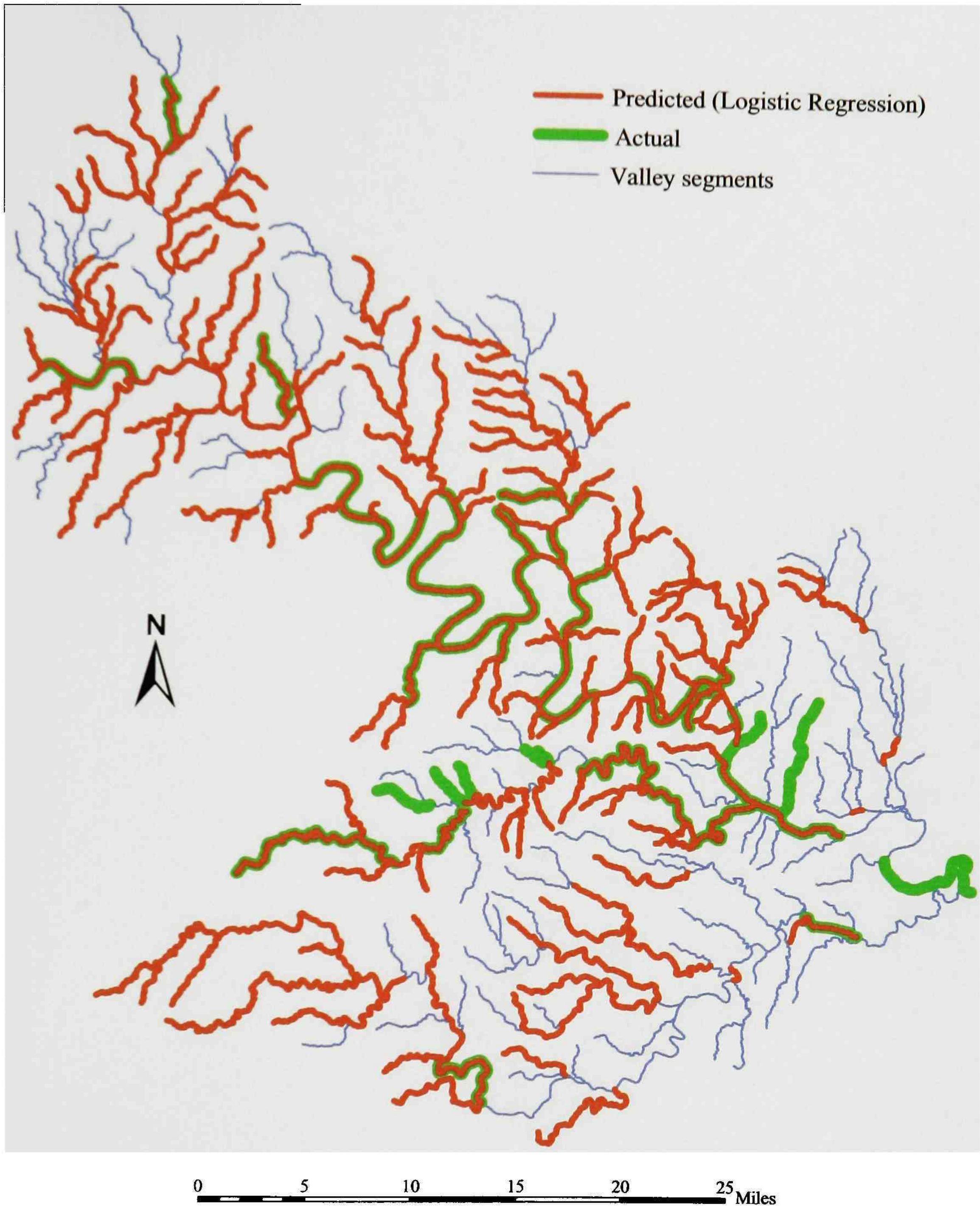

Figure 101. Predicted occurrence of *Lepomis auritus* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

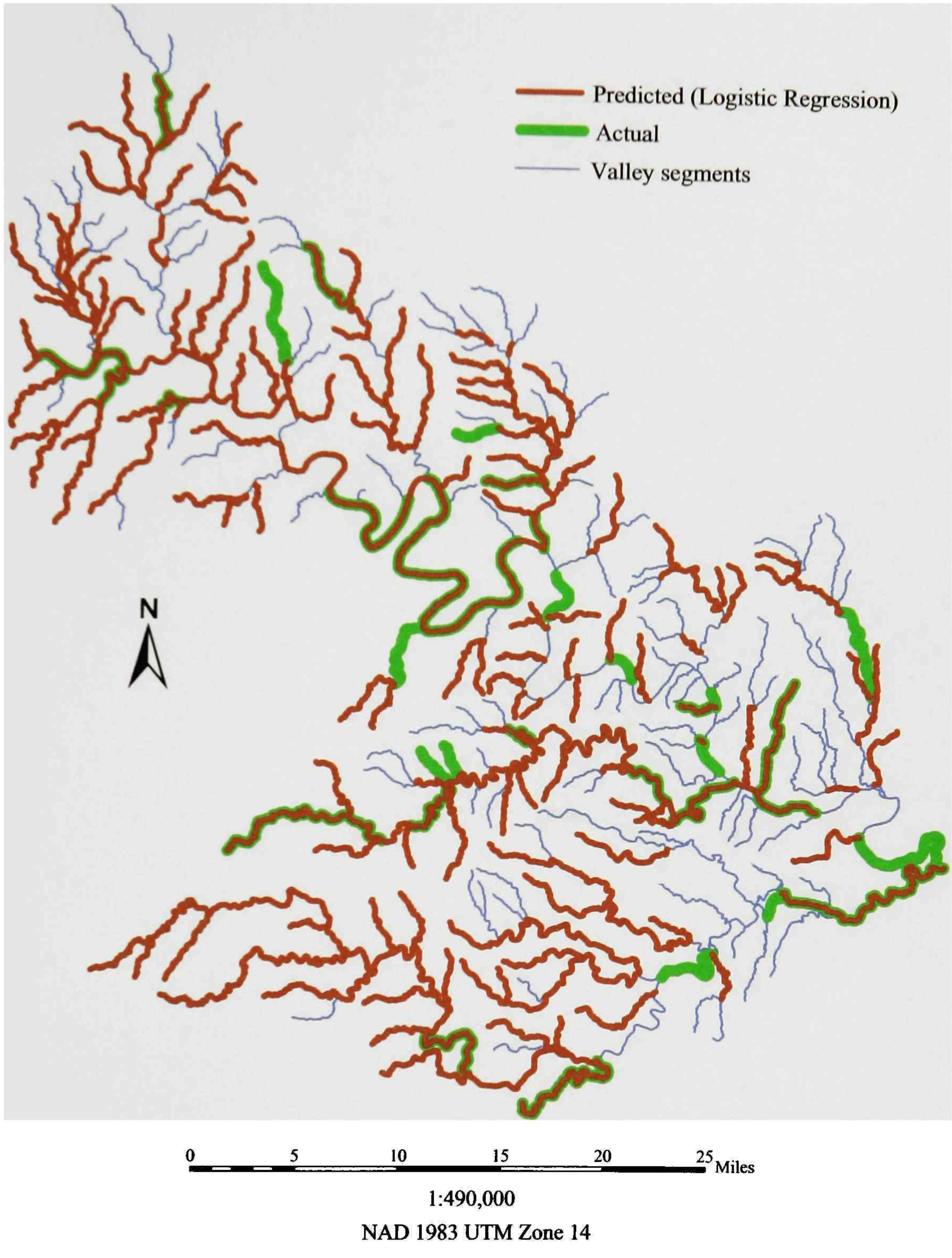

Figure 102. Predicted occurrence of *Lepomis cyanellus* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

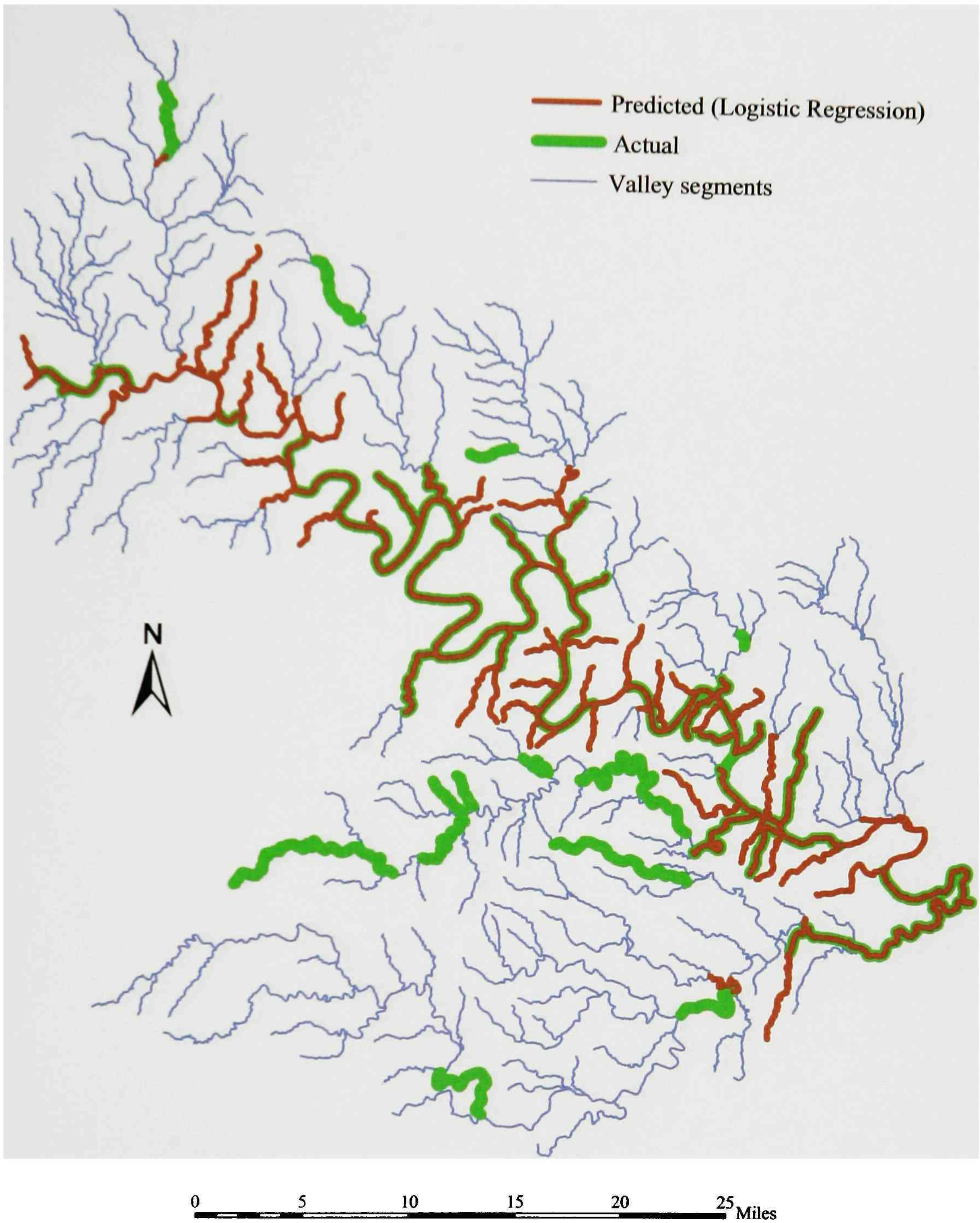

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Figure 103. Predicted occurrence of *Lepomis macrochirus* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

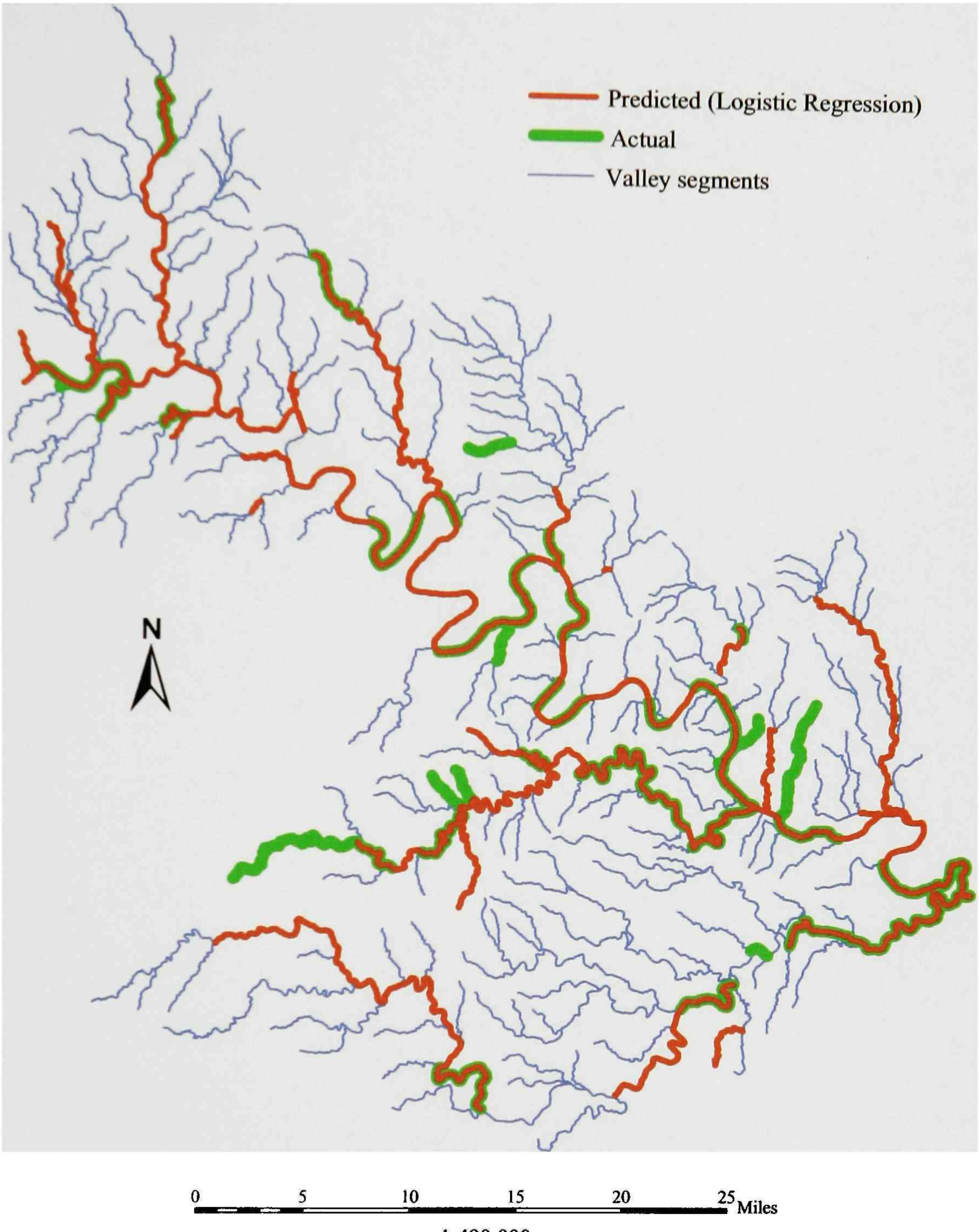


Figure 104. Predicted occurrence of *Lepomis megalotis* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

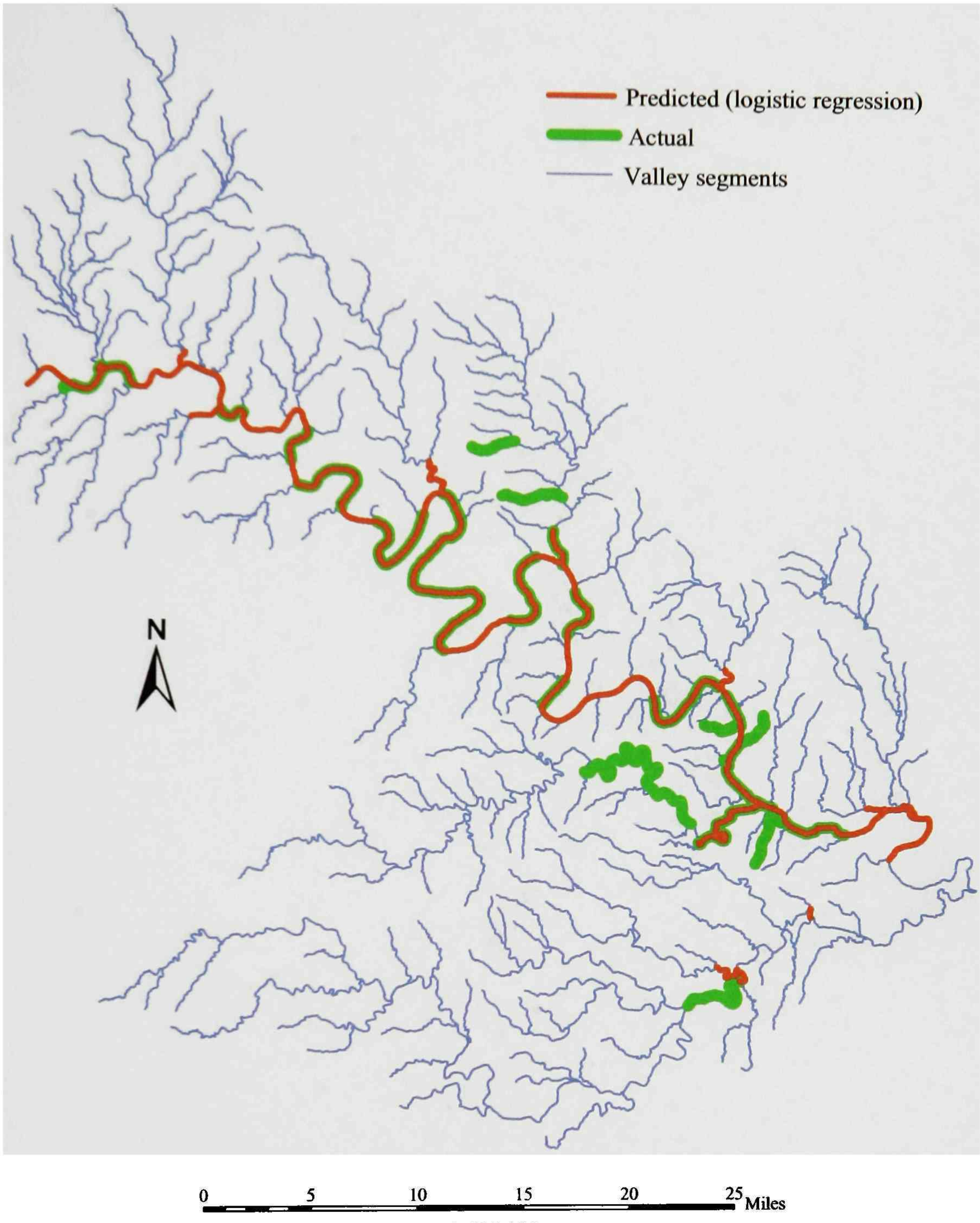


Figure 105. Predicted occurrence of *Lepomis microlophus* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

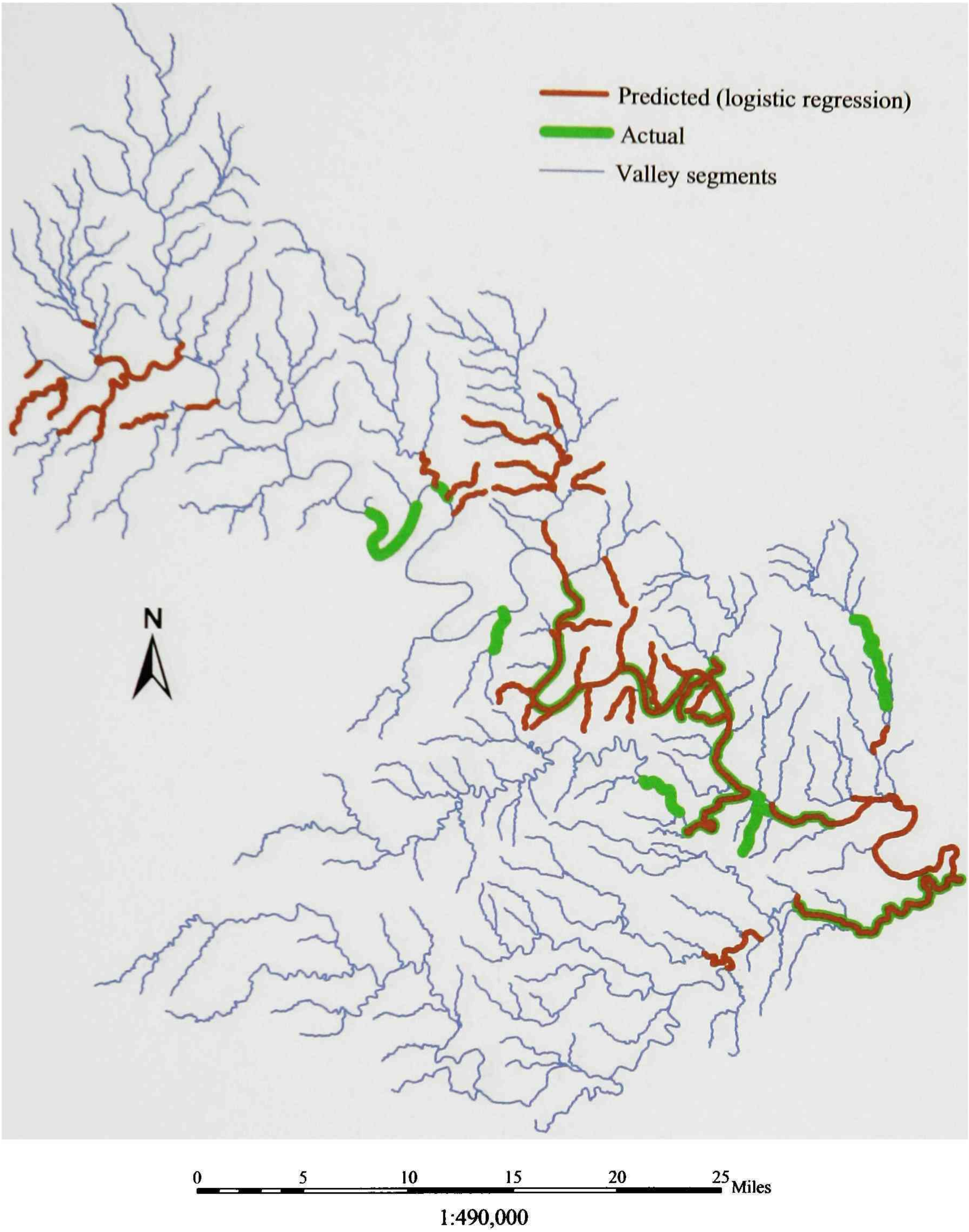


Figure 106. Predicted occurrence of *Lepomis punctatus* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

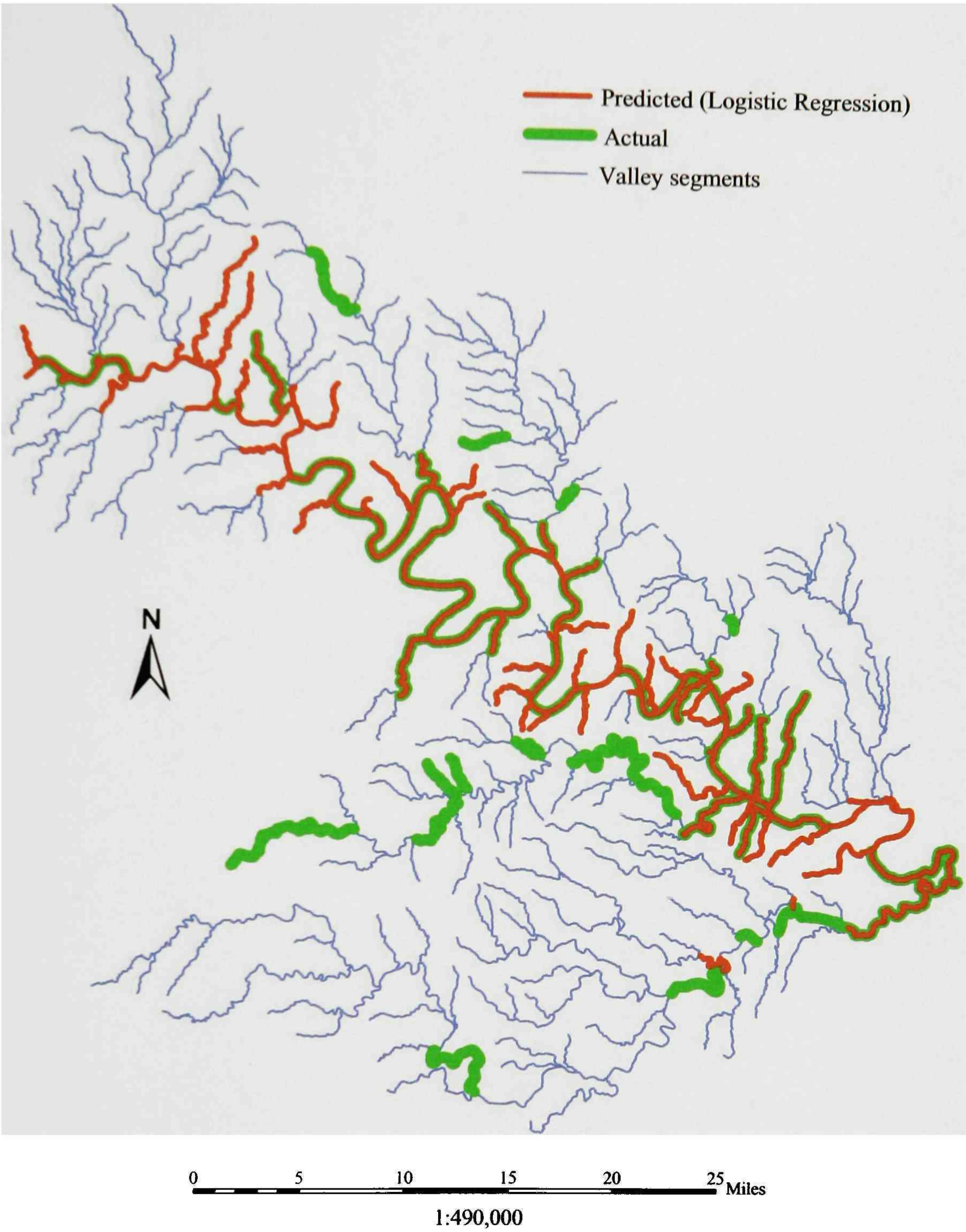


Figure 107. Predicted occurrence of *Micropterus salmoides* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

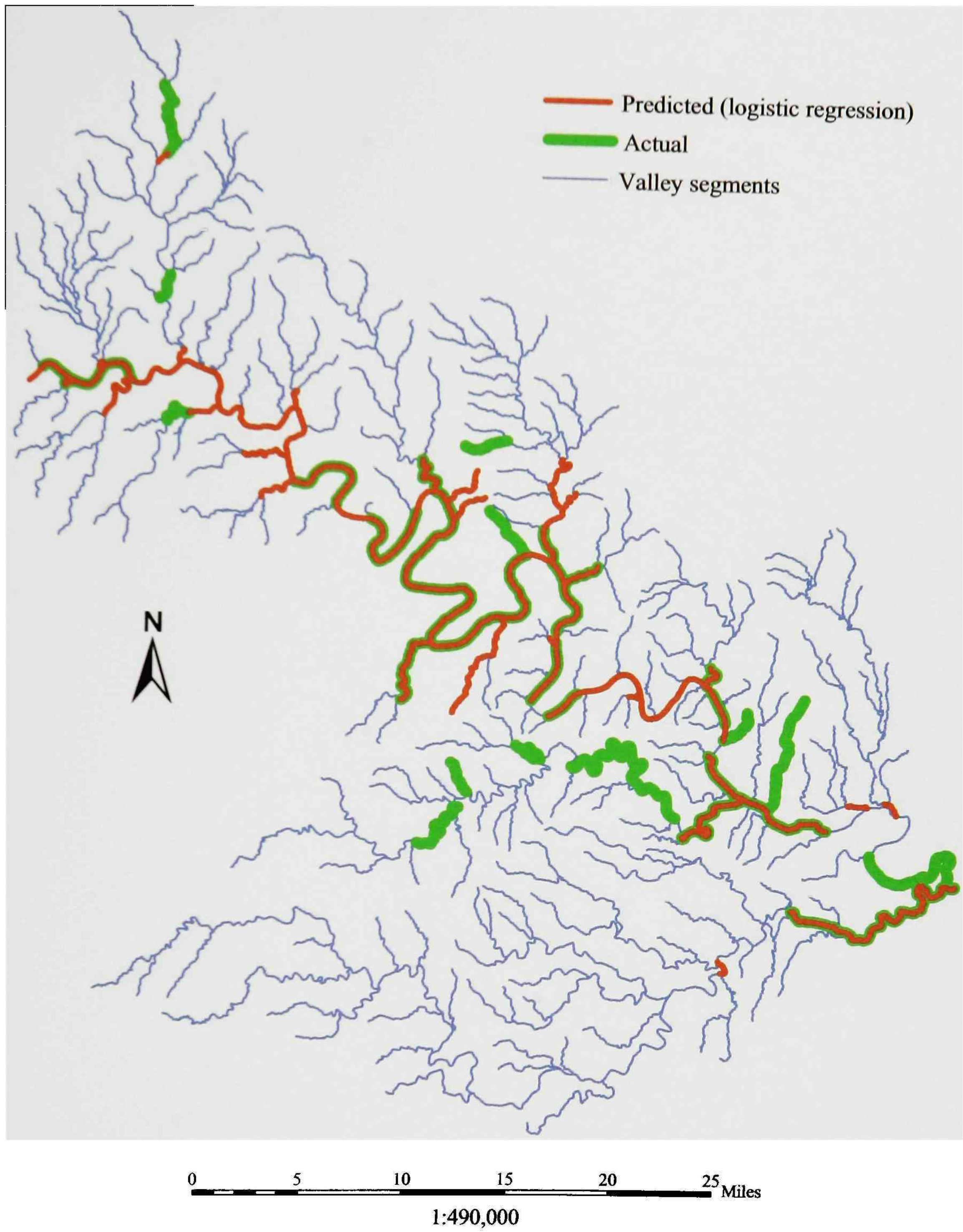


Figure 108. Predicted occurrence of *Micropterus treculii* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

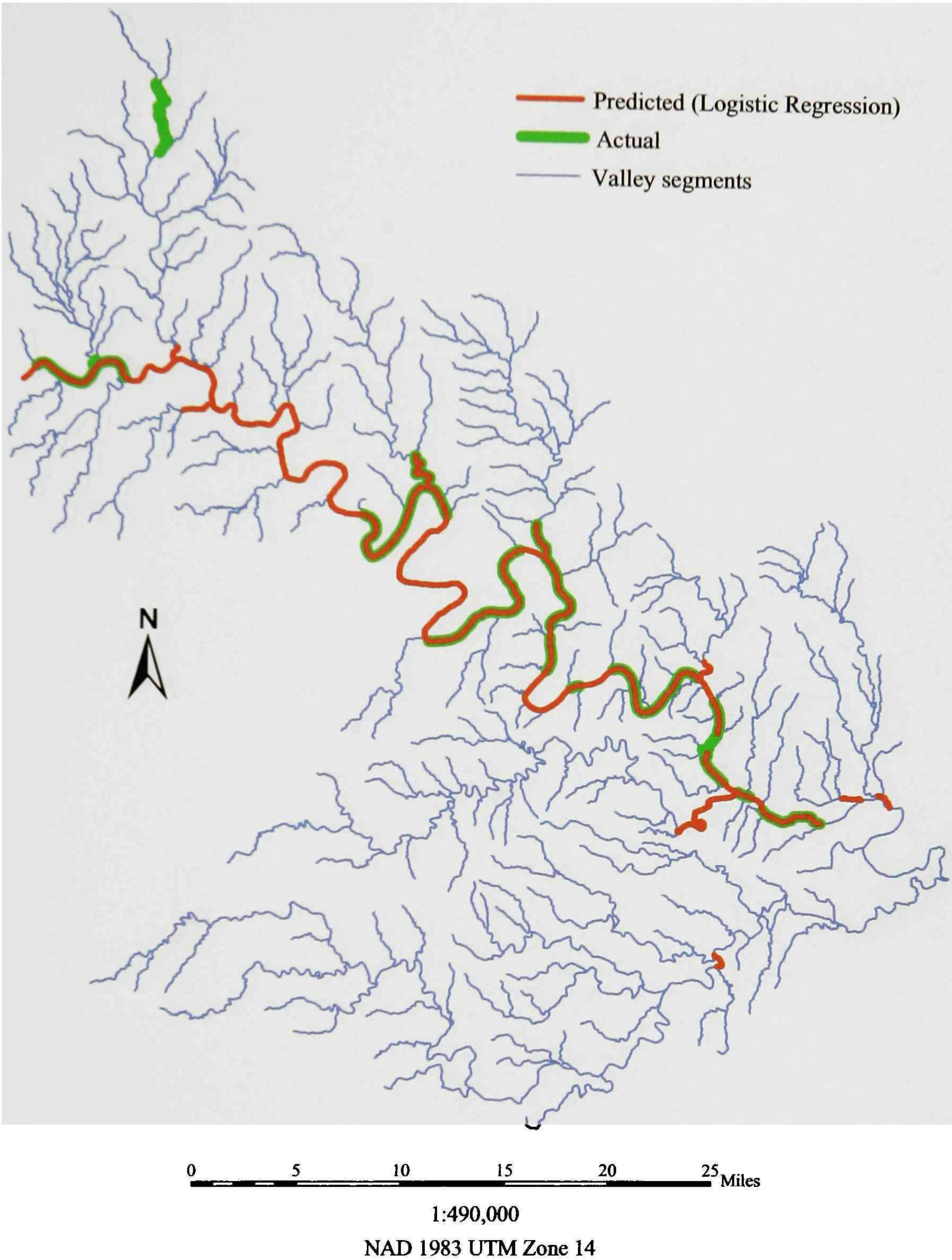


Figure 109. Predicted occurrence of *Aplodinotus grunniens* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

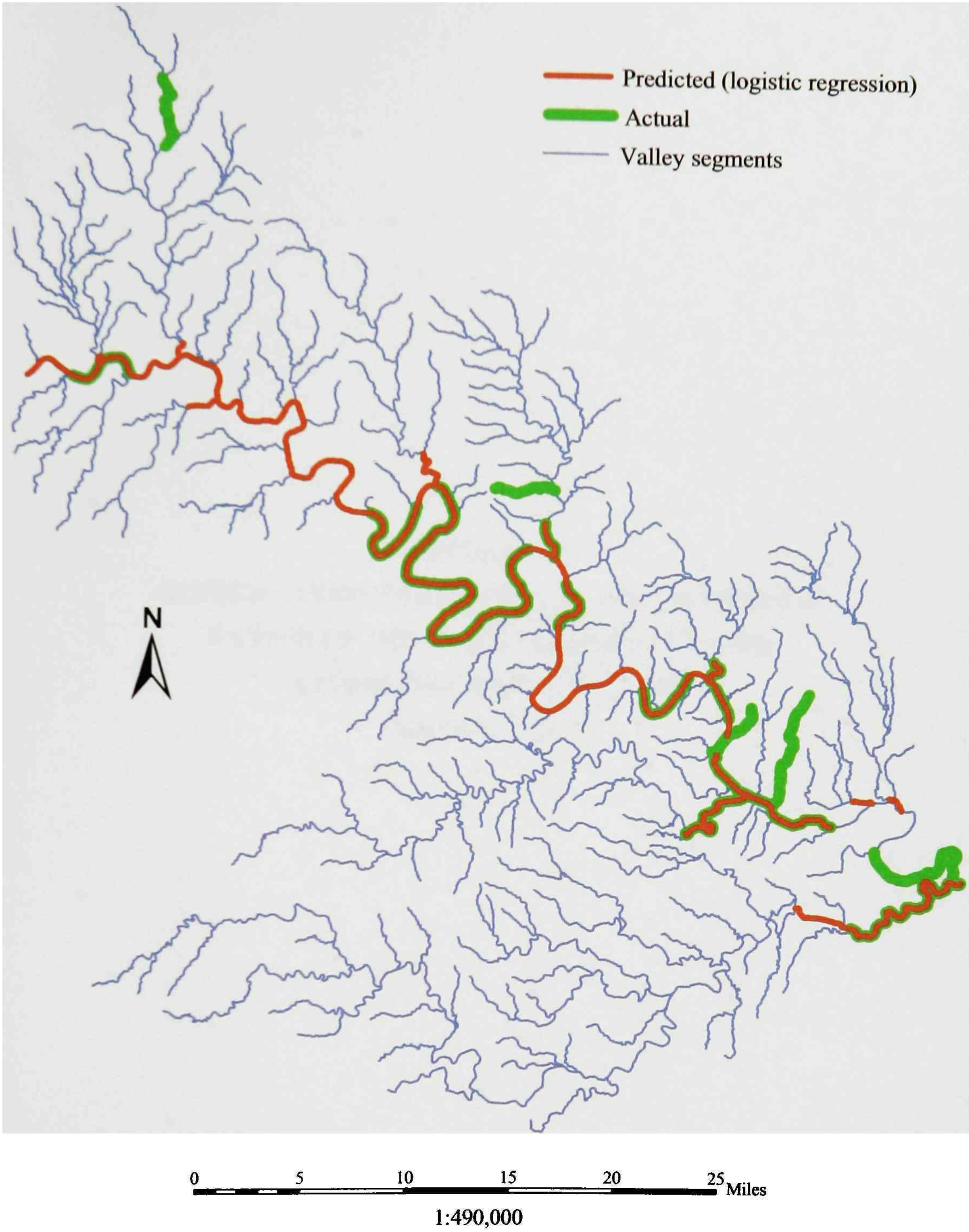


Figure 110. Predicted occurrence of *Cichlasoma cyanoguttatum* using Logistic Regression in the Hydrologic Unit 12090205 of Central Texas

APPENDIX E

CONSERVATION PRIORITIES AND THE PROCESSING LAYERS OF THE VALLEY SEGMENTS IN THE HYDROLOGIC UNIT 12090205 OF CENTRAL TEXAS

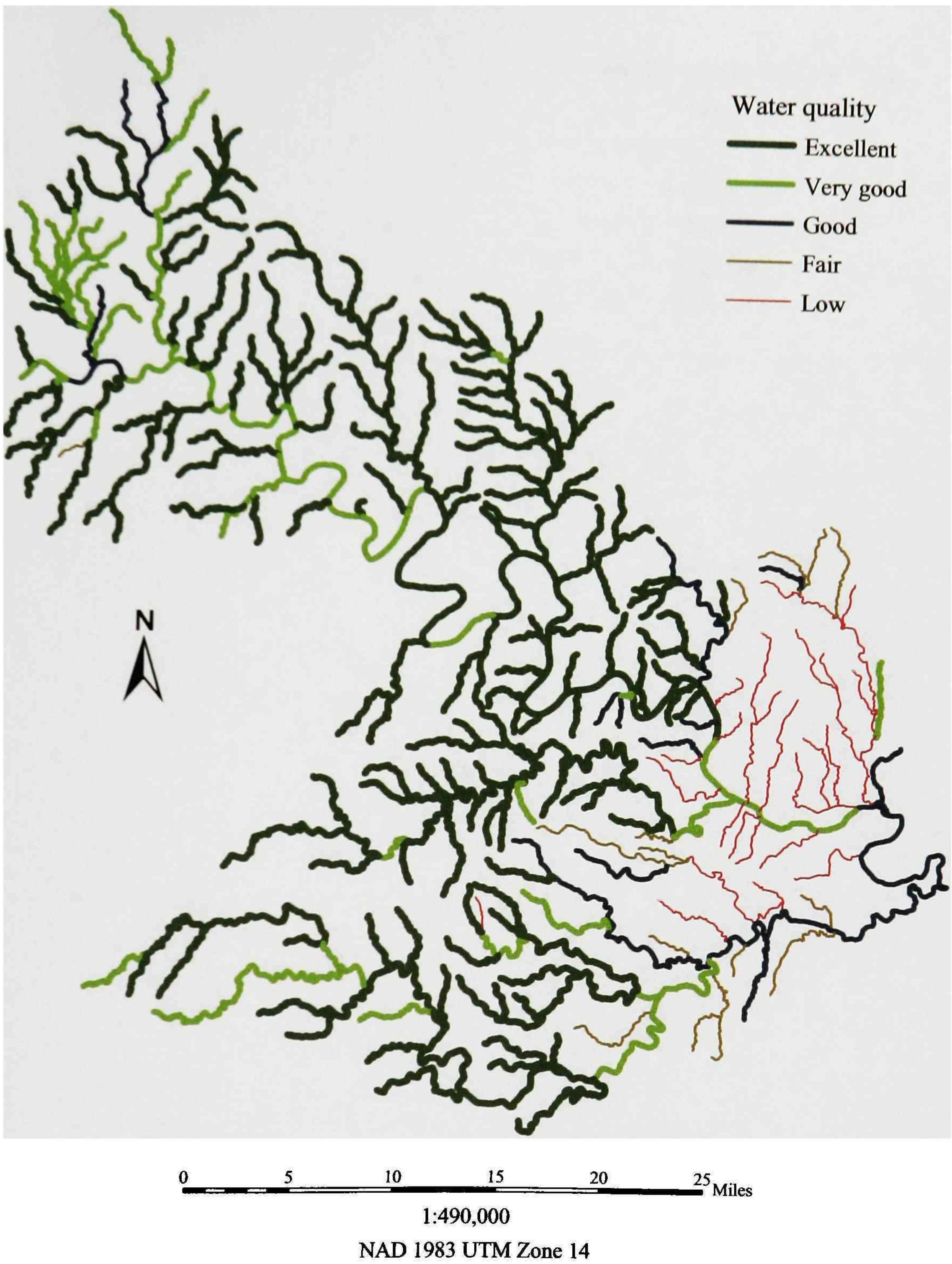


Figure 111. Water quality of the valley segments in the Hydrologic Unit 12090205 of Central Texas

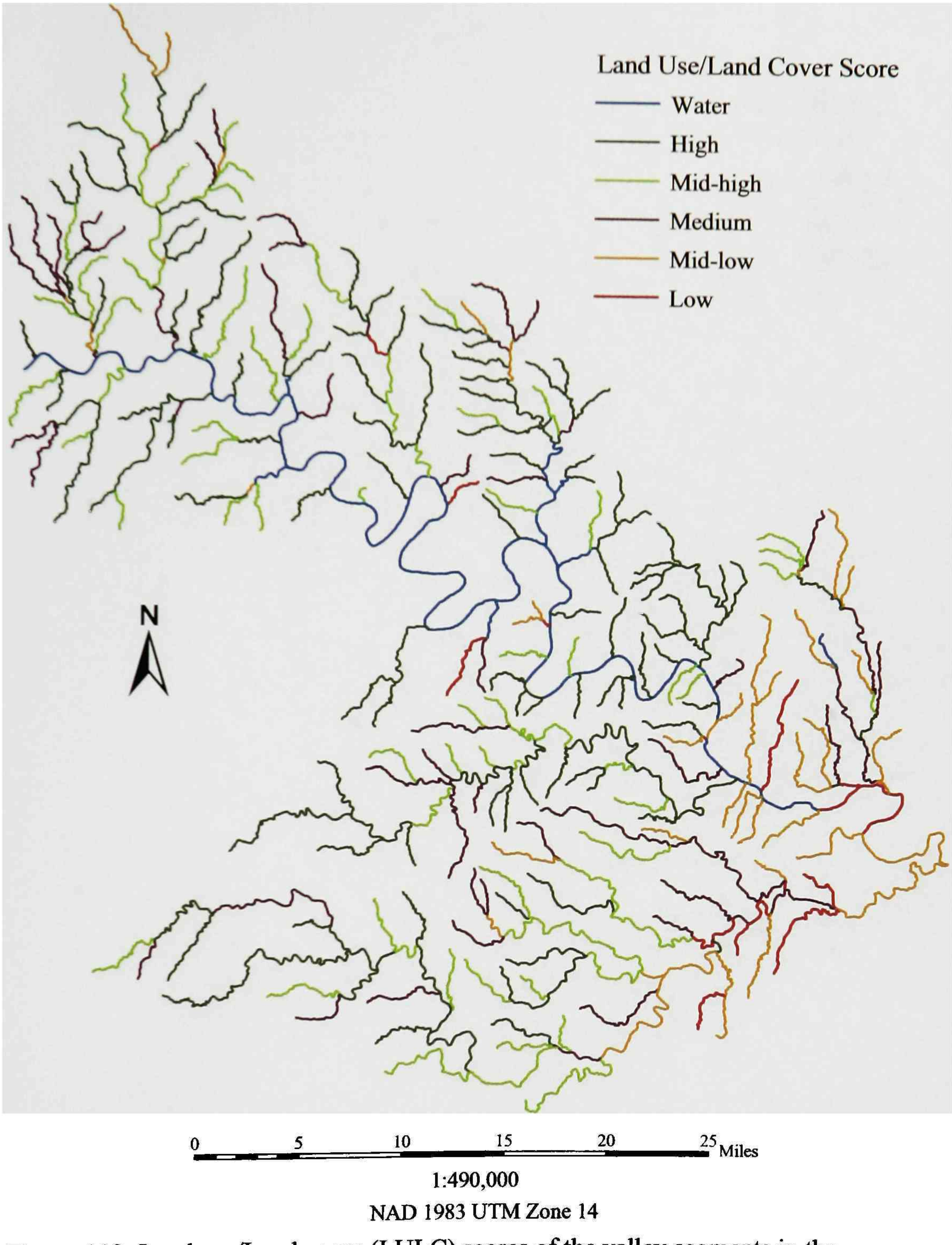


Figure 112. Land use/Land cover (LULC) scores of the valley segments in the Hydrologic Unit 12090205 of Central Texas. The segments with LULC code 5 (Water) were not evaluated.

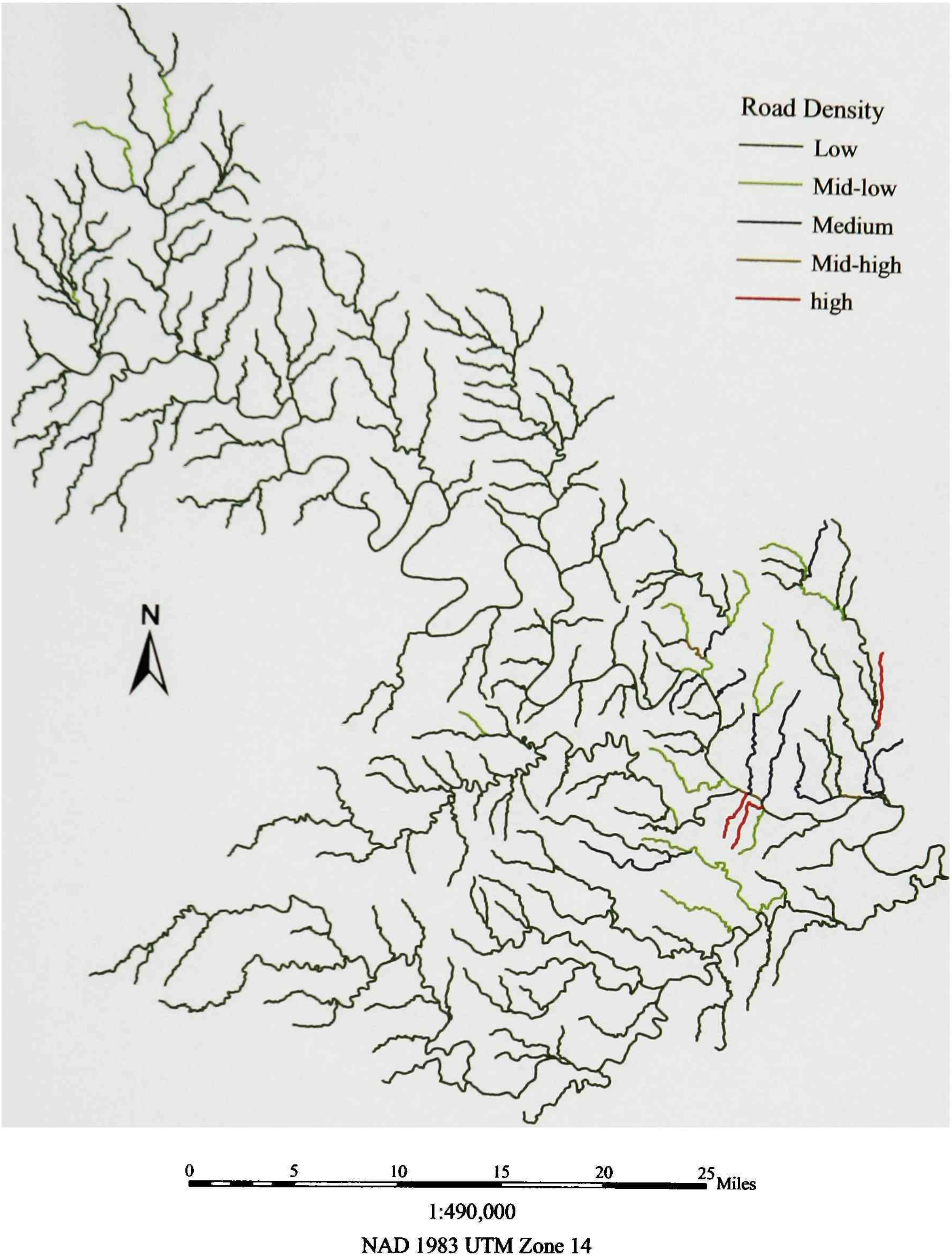


Figure 113. Road/Railroad Densities of the valley segments in the Hydrologic Unit 12090205 of Central Texas.

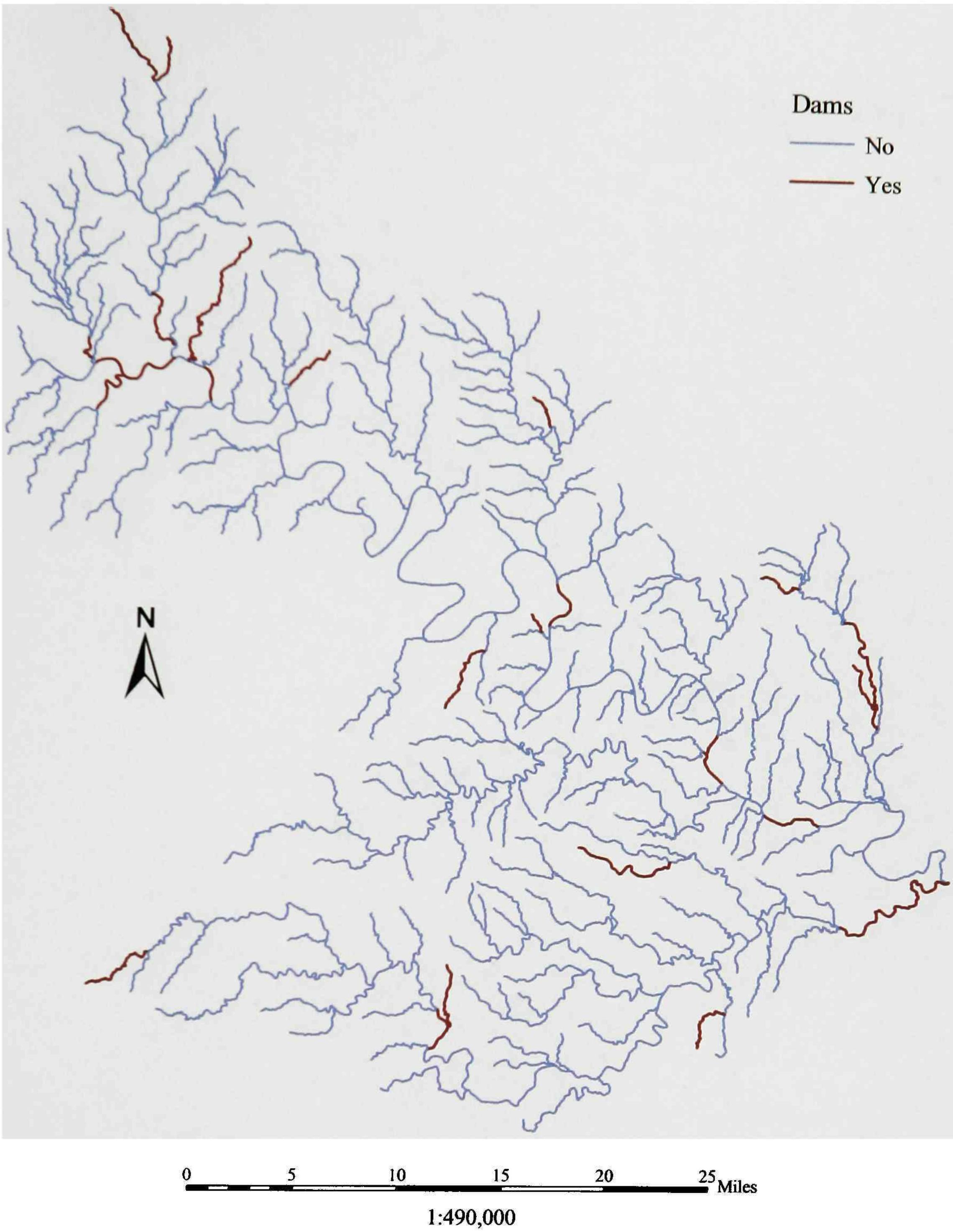


Figure 114. Dams on the valley segments in the Hydrologic Unit 12090205 of Central Texas

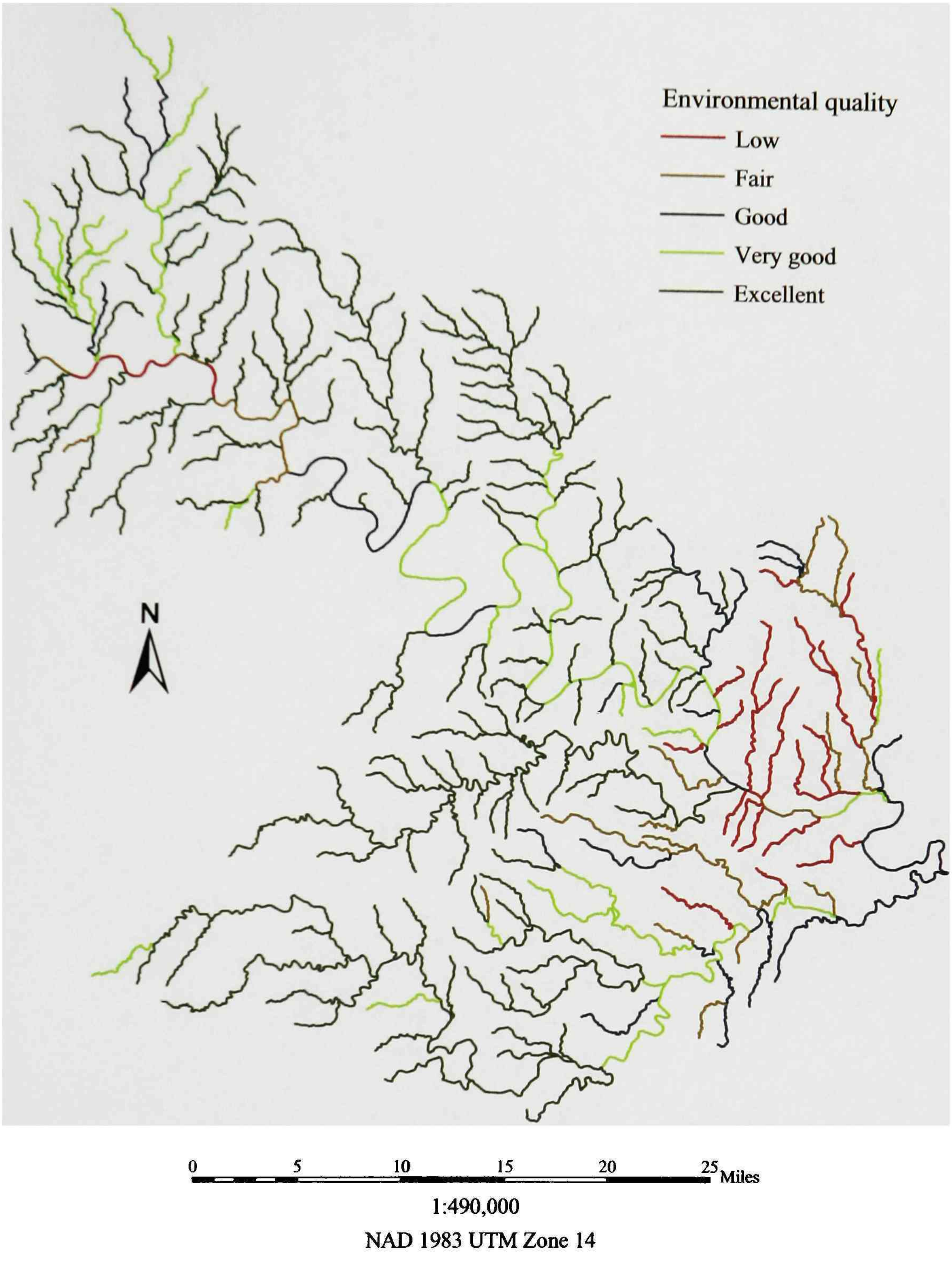
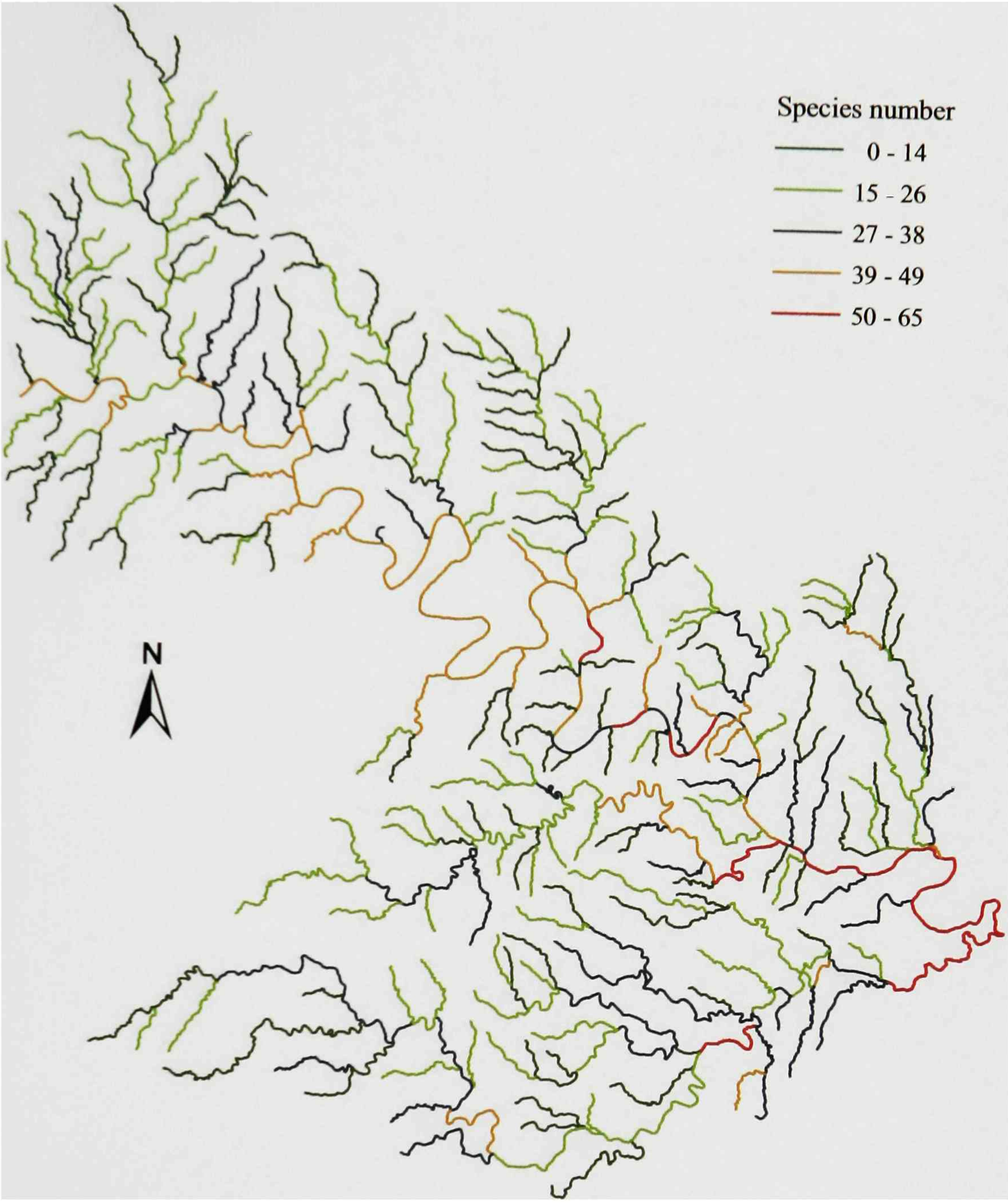


Figure 115. Environmental quality of the valley segments in the Hydrologic Unit 12090205 of Central Texas



0 5 10 15 20 25 Miles

1:490,000

NAD 1983 UTM Zone 14

Figure 116. Species number of the valley segments in the Hydrologic Unit 12090205 of Central Texas

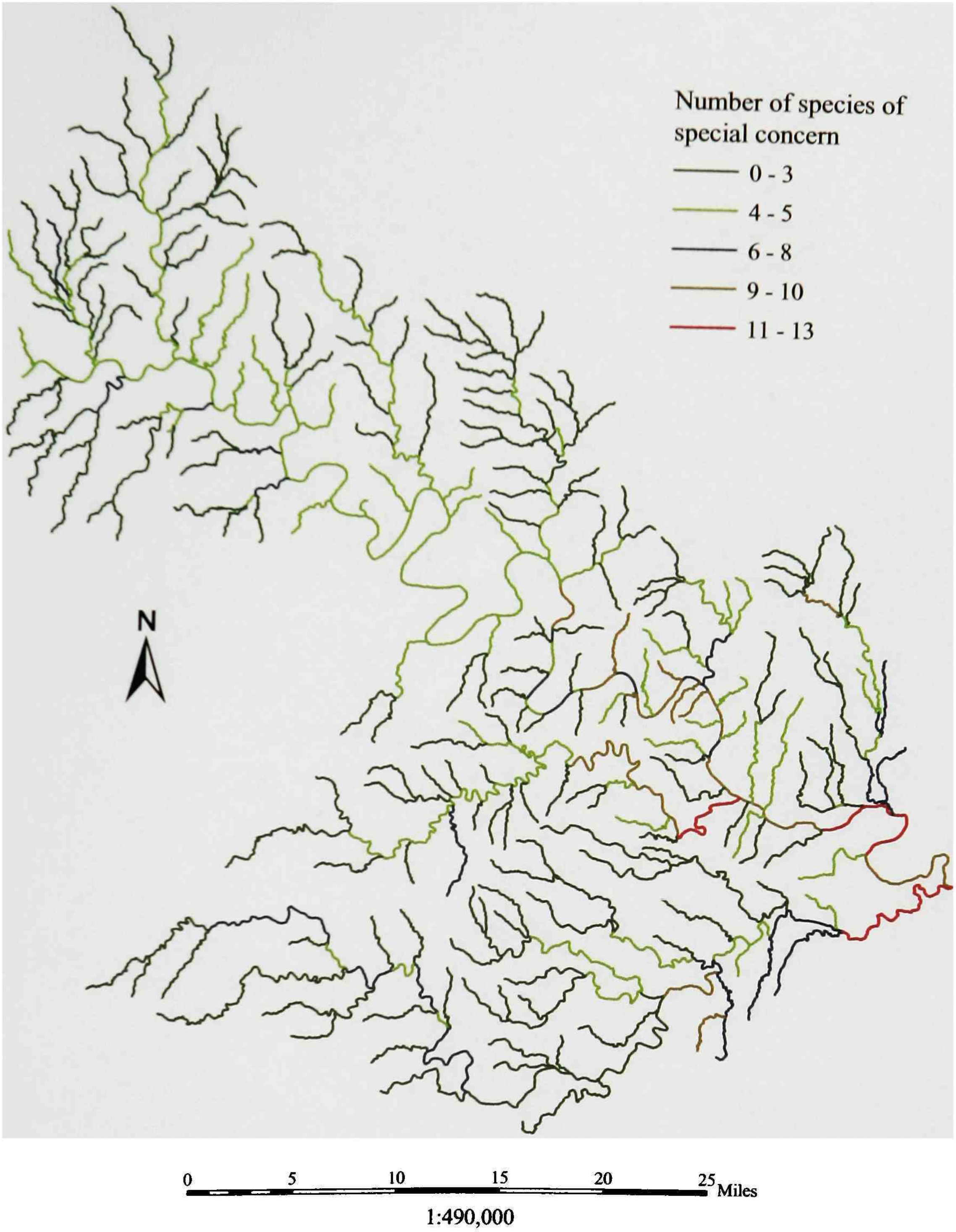
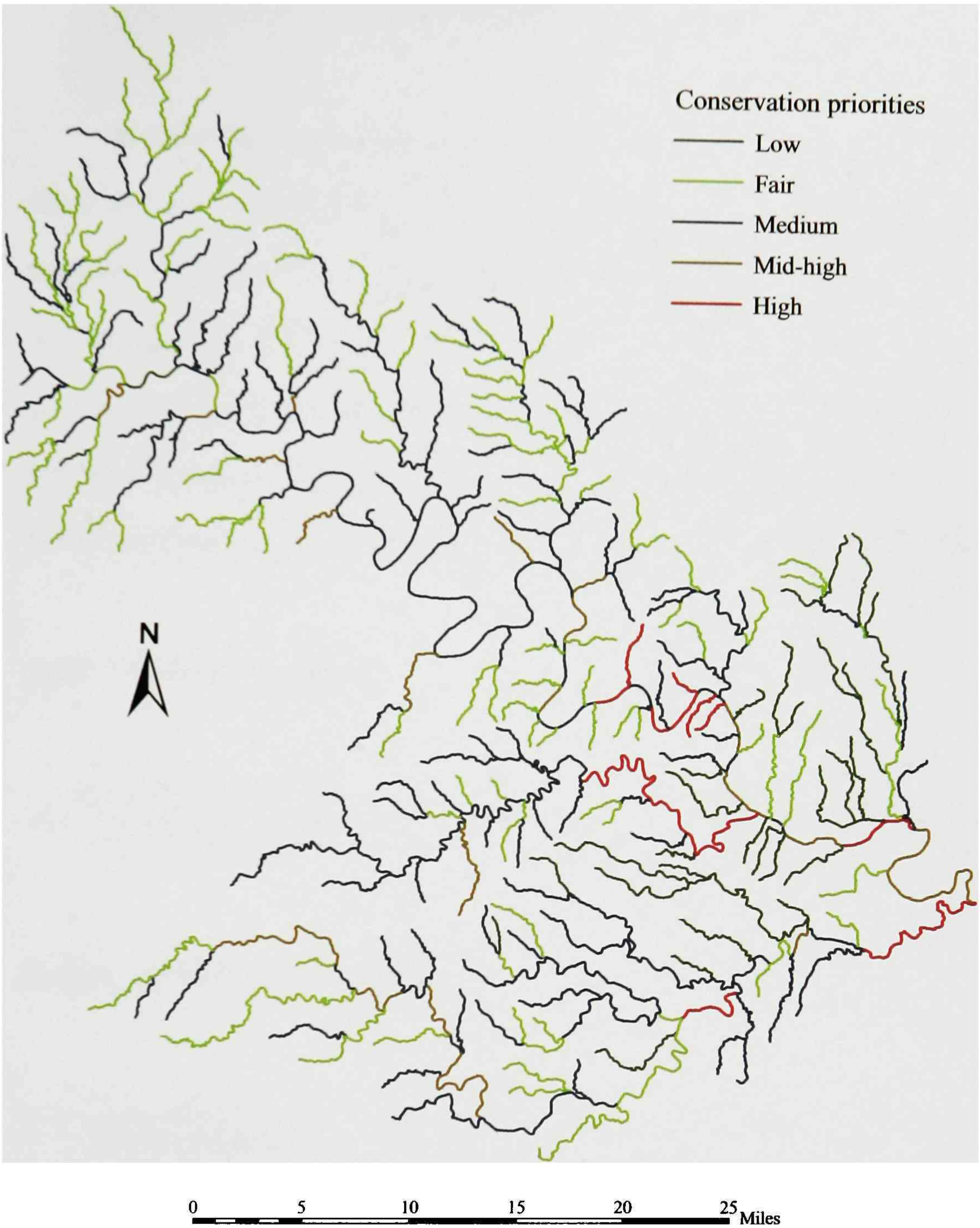


Figure 117. Number of species of special concern in the valley segments in the Hydrologic Unit 12090205 of Central Texas



1:490,000

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Figure 118. Conservation priorities of the valley segments in the Hydrologic Unit 12090205 of Central Texas

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